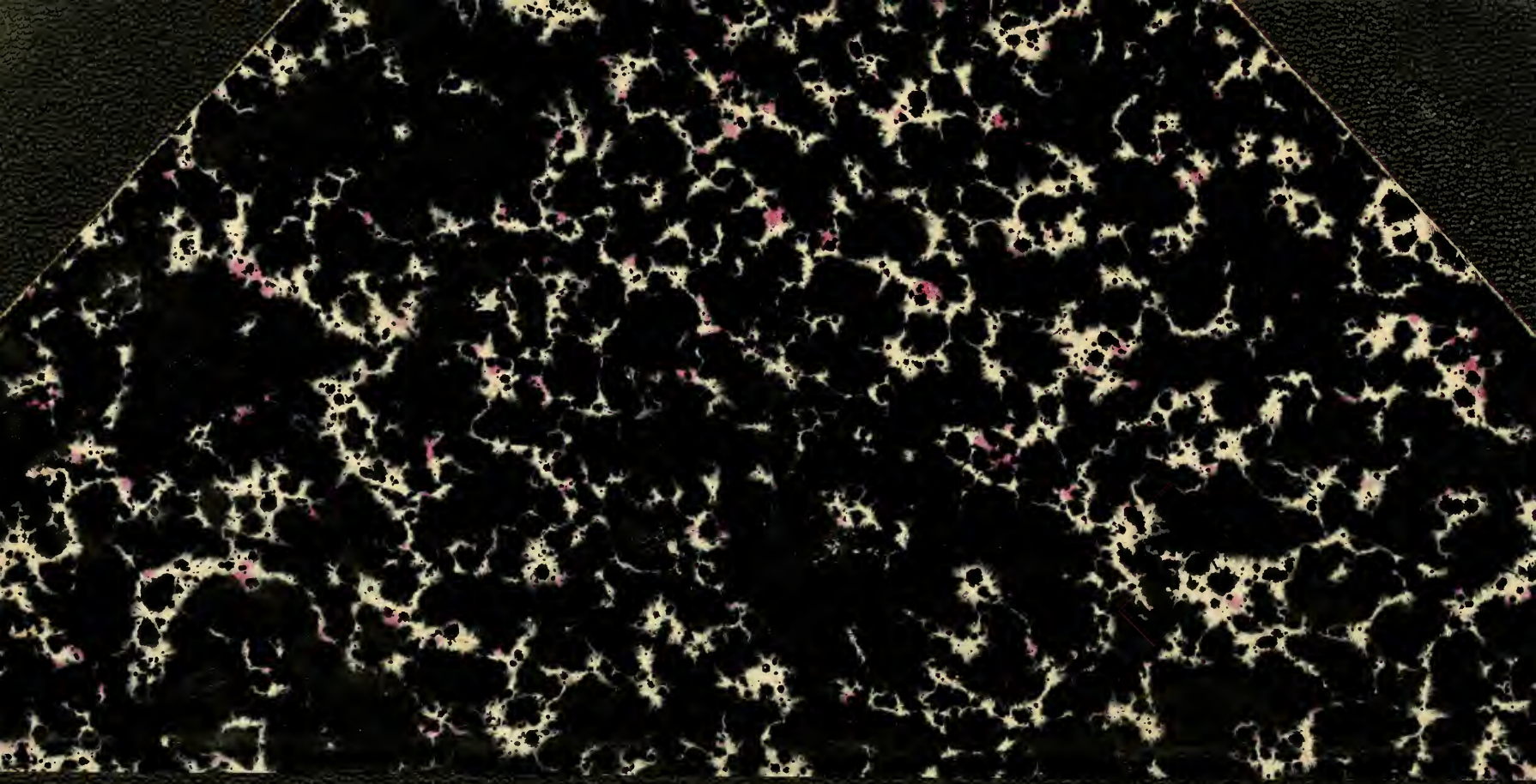

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OF

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DRAINAGE MODIFICATIONS IN KNOX, LICKING AND COSHOCTON COUNTIES.

With Plates I—III.

By W. BLAIR CLARK.

Granville, Ohio, June, 1902.

Bulletin of the Scientific Laboratories of Denison University.
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DRAINAGE MODIFICATIONS IN KNOX, LICKING AND COSHOCTON COUNTIES.[1]

By W. Blair Clark.

It is not intended in this article to discuss the whole drainage system of these three counties, or even that of any one of them. The area to be studied may be bounded roughly by the triangle whose vertices are located at Newark, Mt. Vernon and Coshocton. This territory is entirely within the hydrographic basin of the Muskingum and practically all its drainage is carried to that river by three streams.

The largest of these three streams is the Walhonding River which, with its upper continuation, Owl Creek, flows along the northern side of the triangle outlined above. This drainage axis is the outlet for all the northwestern and northern portions of the region under consideration. In addition, the Walhonding receives very considerable contributions from the North, chiefly by way of Mohican and Kilbuck Creeks. With the exception of the lower part of the former, these two creeks were not studied in this investigation.

South of the Walhonding is Wakatomaka Creek, second in order of the three streams indicated above not only in location but in size as well. The axis of this creek takes a general southeasterly direction through the heart of the area under review. It drains, perhaps, rather more than a third of the triangle.

Lastly, the Rocky Fork is a small creek confined almost exclusively to the northeastern part of Licking County, and draining quite approximately that whole section of the county, an exception being found along the extreme eastern border which is drained by the Wakatomaka.

A clearer idea of the relations of these streams may be had

[1] Presented to the Department of Geology and Botany of Denison University as a Thesis in pursuing work for the degree of Master of Science.

by referring to Plate I., which is a sketched map of the drainage whose central outlines have just been indicated. Even a casual study of this map can hardly fail to reveal peculiarities in the drainage which it represents. Perhaps the first of these to catch the eye is the fact that the North Fork of the Licking receives no tributaries from the East, all the water that might be expected to come into it from that direction flowing off by way of the smaller and more tortuous Rocky Fork, which rises almost in the valley of the North Fork. Again, Owl Creek leads into a roundabout course some drainage that one might reasonably suppose ought to come down into the North Fork. This supposition is all the more rational when it is known that the headwaters of both Owl Creek and the North Fork are in the same preglacial valley. Another strange feature is the irregularity of the Wakatomaka system. Although its axis maintains a generally southeasterly direction, the main stream itself is extremely tortuous and its tributaries preserve nothing like normal parallelism.

Having noted some of these pecularities it will not be out of place next to outline briefly the map study which served as a preliminary to the field study. The working hypotheses with which we entered the field were based upon this map study in connection with the work already done by Professor Tight in adjacent regions to the South and Northwest. Indeed it will readily be understood by those who have followed the investigation upon glacial stream-modification in Ohio that the work in this region was undertaken with the idea of correlating changes found here with those already worked out in adjoining territory.

Some years ago, while engaged on his researches in the neighborhood of Hanover and the Licking Gorge [1], Professor Tight had noticed a rather large preglacial valley tributary to what he has called the Old Newark River. This old tributary came seemingly from the Northeast and entered the main valley at a point nearly opposite Hanover. But at present it brings

[1] TIGHT, W. G., Bull. Sci. Lab. Den. Univ., 8^2:35-63, 1894.

into the valley no stream larger than a wet weather run. Lack of time forbade exploration of this old tributary and the determination of the area formerly drained by it was left as a problem for the future. Later, when eroded cols had been located above Walhonding on Owl and Mohican Creeks it was felt that the mouth of the Walhonding was too far east to have been the outlet for the middle basin of that stream in a normal system of drainage. So after map study it was concluded that the most probable outlet for this middle portion of the Walhonding (possibly including Kilbuck Creek also) was by way of an axis following West of South and emptying into the Old Newark River as the tributary whose mouth had been already observed opposite Hanover. At the same time the possibility of this section of the Walhonding having gone out to the West, passing somewhere near Bladensburg, was noted and discussed. (In this case it would have emptied into the Old Mt. Vernon River, a pre-glacial stream located by Professor Tight in the course of some work the result of which has not yet been published. Its location may be noted on Plates II. and III.)

Passing next to the Wakatomaka, it was thought that an eroded col would probably be found somewhere near the point where this creek crosses the line between Knox and Licking Counties. In this case all the upper waters of this stream would have gone originally West or Northwest into the Old Mt. Vernon River, while its middle course would have been crossed at some point by the preglacial stream emptying opposite Hanover. And its lower waters would have entered the Old Newark Valley, as at present, near Frazeysburg. Reference to Plate II. will make clear the fact that the Wakatomaka in that portion of its course between Frazeysburg and Dresden is now flowing up the valley of the Old Newark River. This reversal, as has been pointed out by Professor Tight's work [1], being due to the glacial dam at Hanover. Hereafter the stream which formerly occupied the old valley opening opposite Hanover will be called the Old Hanover Creek. Whether that

[1] TIGHT, W. G., Bull. Sci. Lab. Den. Univ., 8 [2]:35-63, 1894.

portion of the Wakatomaka which lies so nearly coincident with the boundary between Licking and Coshocton Counties formerly constituted a part of the main axis of the Old Hanover Creek or whether the tributary which parallels this portion of the creek about two miles further to the East may have previously received its headwaters from further North, and hence have been the main line of drainage, was left an open question for the field work to settle.

Finally, with regard to the Rocky Fork, it seemed quite evident that from the point where that stream turns South its upper waters must, in preglacial times, have flowed either northwest into the Old Mt. Vernon River or southwest into the North Fork. They may have even been divided, portions going into each basin. In how far these hypotheses accorded with the facts is now to be seen. As the field work had to be done on Saturdays and during brief two- and three-day recesses in regular school work I found it impossible to make a strictly consecutive study of the whole area. Consequently the single-day periods were utilized for working up that portion of the region which was near at hand, while more distant sections were reserved for times when trips of a few days length would make visits to them more profitable.—All of which is to explain why no attempt will be made to present the facts in the order in which they were gathered and studied.

As it was at first deemed that the location of the preglacial Walhonding would have an important bearing upon the settlement of minor modifications in its locality, that part of the subject will be taken up first. After preliminary trips, one up the Walhonding from Coshocton to some four miles above Warsaw, the other up the Old Hanover Creek, it was decided that the most economical as well as the surest method would be to traverse the present water shed extending from Coshocton westward between Wakatomaka and the Walhonding. Such a trip was taken in company with Professor Tight and resulted in demonstrating that the water shed referred to is a rock ridge throughout its whole length and contains no gaps sufficient either in width or depth to have ever carried even a small part

of the Walhonding drainage. Of course there are the usual indications of piracy from one side of the ridge to the other, but only very limited areas are affected by any of these cases. Many of these piratical modifications, however, are of sufficient magnitude and local interest to repay well the time that would be required to work them out carefully. The discovery of the high and unbroken character of the ridge between these two streams demolished what had been considered the most important of our working hypotheses. However the fact had been demonstrated beyond a peradventure, so a new turn was taken and the possibility observed that perhaps one of the two cols that had been located on Owl and Mohican Creeks had not been based on sufficient data. Professor Tight had located these cols some two years previously, and in order that the work might be reviewed with as little bias as possible, it was decided that the writer, who had not been on the ground before, should make a trip into that region. Professor Tight suggested in a letter that probably no eroded col would be found on the Mohican. The writer's opinion was that none would be established on Owl Creek. In the sequel it was demonstrated that both suggestions were untenable and the original inferences the only ones that could be supported by the evidences of the field. Leaving the old Mt. Vernon River at the little village of Howard, Owl Creek enters the mouth of a pre-glacial valley which gradually narrows and whose rock floor gradually rises as Millwood is approached. In the lower portion of this valley its floor is covered to an undetermined depth with bowlder clay, and at a point a mile or such a matter from Howard the valley is filled more than half way across with a heap of morainic material rising 50 feet or more above the level of the present valley floor. As one approaches Millwood the glacial drift thins out so that there is left but a comparatively shallow stratum of soil on the rock floor of the old valley, and the creek itself has cut a gorge into this rock floor. The maximum depth attained by this gorge probably does not exceed 40 feet. This maximum depth of gorge, accompanying the maximum elevation of the old rock floor, occurs perhaps a mile East of Millwood. From

this point eastward the valley widens and deepens again. Very soon it begins to fill again with deposited material, probably the most of it carried in by the glacial stream. Two miles above the junction with Mohican marked terraces are seen. At a point rather less than two miles above the junction of the two streams a somewhat startling narrowing of the valley was noted, but a careful examination failed to reveal any decided signs of an eroded col. And under the circumstances of the col further up stream it would require very convincing evidence before I would locate an old col at this point.

As one comes down into the valley of the Walhonding it is at once evident that the lower part of Owl Creek, that part below the Milwood col, and the Walhonding, originally formed a single continuous axis, to which the drainage brought in by what is now the lower portion of the Mohican made only a very inconsiderable addition. Now the last named stream probably brings in more water than Owl Creek. At the point of junction and for a considerable distance up stream from that place the valley of the Mohican is deep and narrow with quite steep walls and a tortuous course—all the indications of an insignificant pre-glacial existence. In another place we have the observation that this character is entirely lost in the upper portions of the stream where it is flowing in the valley of the Old Mt. Vernon River.

From its formation to Coshocton, a distance of some 20 miles, the Walhonding winds about on the flood plain of an old pre-glacial valley. Rock cliffs all along this valley, showing where long points between tributary hollows and ravines have been cut away, may be due in part to a recent period of rapid erosion as by the action of glacial waters, and in part to the ordinary phenomena of stream action. Throughout the whole distance from the junction of Owl and Mohican Creeks to Coshocton there is not the sign of a gorge to indicate the possibility of an eroded col. At no place is the Walhonding flowing on rock bottom where such rock bottom represents the maximum depth of the pre-glacial drainage for that immediate section of the valley. And if we restore the cols on Owl

and Mohican Greeks, together with another located by Professor Tight near Millersburg on Kilbuck Creek, the hydrographic basin of the Walhonding would be completely rock bound except at the point where it opens into the valley of the Muskingum at Coshocton. Our only possible conclusion, therefore, is that the pre-glacial Walhonding must have emptied its waters into the Old Newark River at the point where it now empties into the Muskingum.

The filling of the Walhonding Valley has probably resulted from both stream deposition and glacial advance up the valley. Exposures in the upper part of the valley where the Toledo and Walhonding Valley R. R. has cut through the terraces show very distinct shingling. But down at Warsaw, there is a dam some 25 or 30 feet high and a few hundred feet broad which almost completely fills the mouth of Beaver Run. I was able to find no very new exposures along this dam at the time of my visit and could discover no evidences either of shingling or of heterogeneous deposition. A plan of the fill did not seem to me to present a sufficiently rounded outline to have been deposited from an eddy, which from its position out of the main current is the only way in which it could have been deposited by water. Its relatively straight contours on both the up and down stream sides indicate that it may be a lateral moraine from a tongue of ice pushed up the valley. And its pebbles and boulders are glacier-worn.

Kilbuck Creek, which empties about two miles below Warsaw, is the Walhonding's chief tributary. As one looks into it on coming up the latter stream it presents a wide open valley comparable in size with that of the Walhonding itself. The lower portion of the stream has not been carefully studied in this connection but reference has already been made to the fact of Professor Tight's having located an eroded col near Millersburg. This old col was but a few miles North of the Coshocton County line, hence the Old Kilbuck and Walhonding Creeks must have drained approximately equal areas. This readily explains the nearly equal sizes of their valleys, while the increased volume of water now coming in from Owl and Mohican

Creeks as against the small amount coming from above the Old Millersburg col furnishes a very acceptable reason for the present disparity in volume of water carried by the two valleys. Most of the topographical features mentioned above have been indicated on the map (Plate II.) showing the old drainage as modified into the new. It is to be noted that the heavy lines representing the pre-glacial valley walls are drawn to indicate the tops of those walls, not their bases.

It has already been mentioned that a preliminary trip was taken up the old Hanover valley. The results of that trip will now be discussed somewhat more in detail. The floor of this old valley, which is a continuation of the Hanover morainic dam, is rolling and more or less cut up by small ravines. Very soon after entering its mouth the drainage is found to be flowing up the valley away from the old main stream. About two and a half miles from the valley's mouth there is another morainic dam rising some fifty feet above the bed of the run. But this obstacle has not been of sufficient elevation to turn the water back over the Hanover dam. The run has made its cut at the junction between deposited material and the old valley wall (west side), so that one side of the gorge is rock and the other morainic material. East of this point the dam slopes down somewhat rapidly to the level of the stream bed again, so that for a distance of two miles further to its junction with the Wakatomaka, near the county line, the run is little more than a ditch winding through the fields and having a very sluggish current. Wakatomaka comes down the drift-filled valley as a much larger stream, but has the same characteristics of a winding bed and sluggish current. Instead of flowing on down the old valley to the Licking, however, the Hanover dam has been high enough to force the waters over a low col in the northwestern corner of Muskingum county, and thus allow them to escape by another route into the Old Newark river. At Frazeysburg they turn up this old river valley (the eastward prolongation of the Hanover dam again prevents them from flowing down the old course) and continue sluggishly to the Muskingum at Dresden. Reference has already been made to Pro-

fessor Tight's previous publication concerning this last mentioned feature of the Wakatomaka's lower course.

Returning to the point where Wakatomaka creek crosses the Licking county line, we will ascend the old valley to the mouth of its principal tributary, Winding Paddy's Fork. At this place it is evident, both from the position and the relative sizes of the two valleys, that the tributary now occupies what was originally the main valley, while the principal stream comes into this valley through what was at one time only a tributary valley. Trips up Winding Paddy's Fork and around its headwaters both demonstrate that it heads normally in the high rock divide. The regular fan-like phenomenon of its head ravines gave rise to some speculation at first, but careful examination indicates that the peculiarity had been wrought by local topographic features and has had no direct bearing on other parts of the problem. From map study we had thought possibly this phenomenon might be due to glacial constriction of a system more widely distributed in former times. But an examination in the field proved the fan to be rock-bound, except at the one point where its waters make their exit into the above named Fork.

Going back now to the Wakatomaka and ascending that stream, we soon find it entering a deep, rocky gorge. On one trip, in descending into the gorge from the high divide on the south, the barometer showed a drop of nearly 400 feet in advancing no more than a quarter of a mile. The cutting is so deep here as to have extended for two or three miles along the stream, hence it is impossible to locate the exact position of the eroded col. It may have been between any one of a half dozen or more pairs of hill tops. But this inability to locate it exactly does not vitiate the proof that a col once existed somewhere along the course of this gorge; for, besides the evident newness of this section of the channel, as compared with sections above and below, this is the farthest up-stream section in which the water is found flowing on rock bottom. Above the gorge the valley widens out until it finally opens, at Bladensburg, into an old pre-glacial valley whose axis lies

nearly due east and west. This Bladensburg valley was the main axis of a small stream, tributary to the old Mt. Vernon river, to which reference has already been made. It is evident that the waters which cut out this old valley flowed toward the West because to the East it heads in the rock divide, then widens and deepens (so far as the rock floor is concerned) toward the West. It was in one of the southern tributaries of this valley that a col was cut down in opening up the new gorge of the Wakatomaka. The filling in this Old Bladensburg Valley is so deep that the tops of the hills immediately bordering the pre-glacial main valley have been entirely covered, and the present appearance is that of a great valley whose sides are the divides bordering the hydrographic basin of the old stream. The appearance of greatness is so deceptive that when we first came upon the view we were sure that we had found the long sought-for outlet of the middle Walhonding. But when we found it heading out in the highest rock divide in this part of the state, and saw, furthermore, that the present floor of the valley is very high as compared with other valleys in the region, we revised our conclusions and decided that its present great width is due to the tremendous filling that it has undergone. This filling consists of the usual deposits found in the glaciated portions of the state—irregularly deposited boulder clay of varying depth and composition. The floor of the valley as now filled up is not level but is rolling with here and there considerable heaps of material as though left by icebergs stranded on some point of rock higher than its neighbors. At the same time the whole region is so completely covered with the debris that it would seem as though the bulk of the deposition must have resulted from the advance of the ice sheet into the valley and all its tributaries. It is to be noted also that this filling of the Old Bladensburg Valley extends up to the very top of the divide separating this drainage from that of the Walhonding. But this is a feature that will be referred to later in another connection.

A clearer view of the Wakatomaka modifications, as well as their relation to the Walhonding system, may be had from a

study of the map (Plate II.) already referred to in connection with the modifications in the latter stream.

In view of the preceding descriptions the changes sketched in the Rocky Fork region will be self-explanatory. Notice that as usual in all this part of the state the mouths of westward flowing streams have been blocked up by the glacial debris until their waters were forced over low cols into adjoining systems, with the final result that new streams were located having their axes at right angles to those of the old streams, but utilizing parts of the old valleys, along with some of their tributaries. It will be seen that Rocky Fork occupies parts of the main valleys and tributaries of two westward flowing pre glacial streams as well as that of an insignificant tributary to the Old Newark River. It now takes practically all the drainage that formerly came to the North Fork of the Licking from the East by way of the two streams, one of whose axes it follows in a reversed direction, and the other of which, after following for a few miles, it crosses. There are two points in the development of the Rocky Fork to which special attention might be called. It will be noticed that where the present stream leaves the largest of the old valleys partially occupied by it two cols have been crossed, one a minor col between two unimportant tributaries of the old stream, and the other located in the great divide extending through this section in a North and South direction. The most probable sequence of events was the forcing of the water across the first col by the easternmost dam in the old valley, followed by the blocking of the valley's mouth by a still higher one that raised the floods above the second col.

A phenomenon that proved quite deceptive is to be found where Rocky Fork comes into this old valley by way of one of its northern tributaries. Some half mile above the junction of this tributary valley with the old main valley, there is a rock cut with precipitous sides forty to fifty feet high. The hills open out above and below into what are evidently pre-glacial valleys, and it would seem clear that this marks the position of an eroded col. At one point along the gorge considerable masses of the rock have been split apart (by the freezing of water in the

crevices) and the place has local reputation under the name "Falling Rocks." Just over the ridge to the East, in the middle one of the three parallel valleys coming down from the northern part of the county, there is a similar, though less striking, gorge. In a tributary to this gorge is an overhanging rock which has received the title of "Raining Rock," given because of the continual dripping of water from nearly the whole of its under surface. The easternmost of the three valleys has no such escarpments as these that have been mentioned, but its hill sides are dotted with huge boulders of the same sort of country rock, viz., Logan conglomerate. It was at first assumed that these two gorges represent the locations of old cols. From map study Professor Tight questioned very seriously the possibility of there ever having been cols at these places, but after going over the ground with me he admitted that my inferences seemed tenable. If these were old cols of course the valleys above them must have had outlets in some other direction, most probably to the West or Northwest. Thorough examination of the whole basin revealed the fact that it is completely rock bound, the only gaps anywhere near deep enough to have drained the old valleys being at the two points already discussed and at whatever point the present stream comes into the basin of this old system from the Northwest. After a more careful and thorough examination at Falling Rocks it was found that if the old valley were restored at that place so as to leave no rock escarpment visible, that point would still mark the lowest outlet to this section of the valley. And the same was found to be true for the gorge on the Raining Rock tributary. The only way left to account for the gorge-like character at these points is the fact that the outcrop of the conglomerate here is much harder and more resistant than elsewhere along these streams.

The same difficulty was experienced on Rocky Fork as on the Wakatomaka in locating the exact position of the old col. Two or three miles above Falling Rocks the valley becomes narrow and gorge-like (without, however, any very prominent escarpments) and there may have been a col across any one of

several places. The change in character of the valley walls above and below this stretch, as well as the deepening of the rock floor of the valley whichever way one goes from it, leave no doubt that there was at some time a col across it. The position chosen in mapping this col was selected after studying the location of the divide on either side of the stream as indicated by lateral drainage.

As shown on the map, the small pre-glacial valley in which Rocky Fork heads was originally tributary to the North Fork of the Licking. It is to be noted that the glacial deposit at its mouth is too low to have been a factor in the cutting down of the col whose removal has permitted reversal of the drainage in this valley. The old valley floor at and above this moraine is so nearly level that a ditch no more than ten feet deep leading out toward the North Fork would in time pirate a considerable portion of the Rocky Fork's head waters. Indeed up to within a very few years this valley floor has been swamp for a distance of one or two miles and entirely unfit for agricultural purposes. All the county maps that I have seen show it a swamp or lake, and it is not yet sufficiently well drained to withstand a wet season.

Before passing from this part of the subject it would not be out of place to call attention to the eroded col that has been located on the North Fork near the Knox-Licking county line. The work and credit of locating this old col belongs with the unpublished article of Professor Tight to which reference has already been made; but its correlation with the modifications about the head waters of the Old North Fork makes necessary a brief mention of it at least in this connection. It is the easternmost erosion in the East-and-West line of the divide between the Old Mt. Vernon and Old Newark Rivers.

In tramping about over this section of the state many evidences were found of the high water level that must have existed West and North of the great divide before and while its cols were being eroded. In several places glacial debris was found on the tops of cols between minor systems lying entirely within the glaciated region. Such cols being covered by the

comparatively quiet waters of the glacial lake, presented shoals for the stranding of floating icebergs. As one of these would be melted another would be caught, and so gradually the col received its accumulation of boulder clay. Another specially noticeable feature of the region is the sudden change from the broad, shallow valleys with gently sloping hill sides West of the main divide to the deep ravines and abrupt slopes that one finds immediately upon crossing to the eastward. In travelling from Bladensburg toward Coshocton we found first a fine rolling country, excellently adapted to cultivation, which extended up to the very brow of the divide. Then suddenly and without the shadow of a gradation in passing from the one character to the other we found ourselves in the midst of as rough and hilly a region as is to be seen in the state. Of course the valleys have not the depth that is to be observed down nearer the Ohio River, but they are just as numerous and broken, with just as little evidence of any leveling influence due to glaciation.

Although the glacier itself, and probably the great majority of the icebergs, did not extend beyond the barrier of the great divide, there is abundant evidence that the water level of the glacial lake was maintained beyond it for some time. Near the tops of the hills along many of the valleys are to be seen well defined beach marks that can be accounted for in no other way so readily as by supposing that they were formed by the action of the surf before the great cols down the Muskingum and Ohio Rivers had been cut away sufficiently to lower the level of the glacial waters. The reader is not to understand that no glacier worn materials are to be found East of the divide. They exist there in abundance, but very few of them on the tops of the hills, or rather cols, as is the case to the West. Practically all such debris is found in the bottoms of the old valleys where it has been deposited by the water coming from the glaciated region during and after the cutting down of the old cols. After the filling in this way of the main axes of the new drainage systems, the tributaries of these systems would fill in the natural course of events with the sediment from their own drainage.

In conclusion the reader is referred to the map, Plate III., showing the "restored drainage" in the region under review. In comparing the old with the new drainage it is not difficult to see that the former has a much better right than the latter to be described as the NORMAL system. Instead of, as at present, four streams flowing directiy across the highest divide in this part of the state, the restoration shows no streams crossing this divide. Secondly, the restored drainage shows that in general the axes of tributaries in any of the systems are parallel. which is as it should be. Again, the old drainage shows uniformity not only in axial directions, but also in the size and shape of its hydrographic basins. In the present drainage these basins are irregular in shape and extent, and in some instances almost inextricably intermingled. This irregularity is particularly evident in the relation of the Wakatomaka basin to those of Owl Creek and Rocky Fork.

It will not be out of place to correlate the work that has been described with that done by Professor Tight in adjacent regions, reference to which has been made several times in the course of the descriptions. In this portion of the state Professor Tight has located the main axes of two quite important pre-glacial streams, to one of which he has given the name "Old Mt. Vernon River" and to the other, "Old Newark River." Both these streams had general southwesterly courses and, in Knox and Licking Counties, the furthest point West at which their valleys are distinctly visible in the topography, approached so near to each other that in the readjustment of drainage due to advance of the glaciers cols have been cut down and the basins of the two streams intermingled. The work of the writer has been to locate the divide between these two old streams and to determine the changes incident to the breaking down of this old divide during glacial times. It is but a small part in the problem of restoring the pre-glacial drainage in the Ohio River basin, but it is presented to those interested in the hope that it is a distinct contribution to that problem. In closing, I wish to express my appreciation of Professor Tight's kindly interest in my work, and of his many suggestions by which I

was enabled to economize both time and labor in the prosecution of field investigations Work that was taken up originally merely as recreation has proved to be more than recreation in that it has become intensely interesting study as well.

GRANVILLE, OHIO, MAY, 1902.

DESCRIPTION OF THE PLATES.

I. A sketched map of the present drainage in parts of Knox, Licking and Coshocton Counties, Ohio By an oversight the location of Mt. Vernon is not indicated. It is situated near the Northwestern portion of the included region as may be seen by reference to Plate II.

II. This shows the pre-glacial valleys of the same region together with their relation to the present drainage as outlined in Plate I. The heavy lines represent pre-glacial valley walls and are drawn to represent the brow of the hills, not their bases. All these old valleys in the western half of the map are filled with glacial debris as well as those in the eastern half which received water from the glaciated region. Dotted portions represent places where this filling rises above the general level of the surrounding flood plains. The wide valley from Coshocton to Newark is that of the Old Newark River, the one in the northwestern portion of the map, that of the Old Mt. Vernon River.

III. In this map the pre-glacial drainage of the section is shown restored It needs no special comment other than to call attention to some changes that have been adopted in naming the old streams. What is designated on the map as the Old Muskingum River should be the Old Newark River. Old Knox River should be Old Mt. Vernon River and Old Wakatomaka Creek, Old Hanover Creek.

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EDITED BY
W. W. STOCKBERGER,
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ON THE OCCURENCE OF APLITE, PEGMATITE, AND TOURMALINE BUNCHES IN THE STONE MOUNTAIN GRANITE OF GEORGIA.

With Plates IV—V.

ON THE OCCURRENCE OF URANOPHANE IN GEORGIA.

By THOMAS L. WATSON.

Granville, Ohio, August, 1902.

Bulletin of the Scientific Laboratories of Denison University.
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ON THE OCCURRENCE OF APLITE, PEGMATITE, AND TOURMALINE BUNCHES IN THE STONE MOUNTAIN GRANITE OF GEORGIA.[1]

By Thomas L. Watson.

Aplite and pegmatite.—Careful field study of the larger and principal granite areas in Georgia, by the writer, indicates the general absence of true aplites therefrom. They have been observed in association with the granite masses only at one locality in the state. Since the border portions of the granite masses are usually covered with a considerable depth of residual decay and are seldom exposed, it is not possible to say whether aplites as border phenomena exist, as described by Kemp,[2] in some of the southern Rhode Island and Connecticut granites.

Several aplite dikes less than six inches in width are exposed in the quarries opened on the northwest side of the huge doming ridge known as Stone Mountain, sixteen miles east of Atlanta (Plate IV). Pegmatites are common associates in the Stone Mountain granite and also in the other larger granite masses examined in the state. They consist chiefly of coarse intercrystallizations of potash (orthoclase and microcline) and soda (albite) feldspars with quartz, subordinate amounts of both biotite and muscovite, and occasionally red garnet and tourmaline. So far as my observation goes, the feldspars in the pegmatite greatly exceed in amount the quartz. The granitic pegmatites are sometimes replaced, however, by those of practically pure quartz. In the Stone Mountain pegmatites the dark minerals, mica, tourmaline, and garnet, are frequently concentrated along the central axis of the dike or vein, rather than distributed through the light-colored quartz-feldspar portions. Where observed the granitic pegmatites are monotonously alike, and present no unusual features.

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[1] Reprinted from the Journal of Geology, Vol. X, No. 2, February–March, 1902. Pages 186—193.

[2] *Bulletin Geol. Soc. Amer.*, 1899, Vol. X, p. 372.

The principal aplite in the Stone Mountain granite is banded with pegmatite, the aplite forming the border next the granite and the pegmatite the middle layer of the dike. The junctions between the granite, aplite and pegmatite are regular, entirely sharp and well defined. Apart from its being more compact and of much finer-grained texture, the aplite is easily distinguished in the hand specimen from that of the inclosing granite by its lighter color—marble white—and by its containing but little mica. Biotite is entirely absent and muscovite is only sparingly distributed through the rock as minute foils. Occasional very small crystals of red garnet are sometimes present.

In thin section the aplite shows no essential difference in mineral composition from the granite, except in the entire absence of biotite and decreased muscovite. The rock is a holocrystalline mass composed chiefly of the potash (microcline and orthoclase) and soda feldspars, and quartz. Microperthitic structure consisting of interlaminated orthoclase and microcline with a second feldspar, albite, is common. Somewhat irregular, stout laths of a well striated acid oligoclase are numerous. The small percentage of CaO, less than 1 per cent., and the increased Na_2O shown in the analysis, column I, indicates the preponderance of the soda molecule (albite), which is corroborated by the microscope. Sporadic inclusions of apatite occur.

Megascopically, the inclosing rock is a compact, medium-grained biotite-bearing muscovite-granite of light gray, nearly white, color. Biotite is only sparingly distributed through the rock, displaying considerable tendency to segregate in places. Thin sections of the granite show quartz, orthoclase, and microcline frequently intergrown with albite as microperthite, considerable oligoclase, muscovite, occasional biotite, and some prismatic inclusions of apatite.

The striking similarity between the inclosing granite and aplite is sufficiently shown in the chemical analyses of the rocks given below.

The analyses show more SiO_2 and less K_2O in the aplite than in the granite, with close agreement indicated in the other

constituents. A striking feature of the analyses is the low percentage of lime with practically no magnesia, and increased

	I.[1]	II.	Ia.	IIa.
SiO_2	74.30	72.56	1.2383	1.2093
TiO_2	none			
Al_2O_3	14.73	14.81	.1444	.1452
Fe_2O_3[2]	0.78			
FeO		0.85		
MnO	trace			
CaO	0.90	1.19	.0161	.0212
BaO	none			
SrO	none			
MgO	strong trace	0.20		
Na_2O	4.61	4.94	.0743	.0796
K_2O	4.52	5.30	.0481	.0563
H_2O (Ignition)	0.21	0.70		
P_2O_5	trace			
Total	100.05	100.55		

I. Aplite, Stone Mountain, Georgia. Watson, analyst.

II. Stone Mountain granite inclosing aplite. Packard, analyst.

Ia. Molecular ratios of I.

IIa. Molecular ratios of II.

soda, which equals in amount the potash, indicating the predominance of the albite molecule over that of the anorthite, and in case of the aplite the nearly entire absence of magnesia harmonizes with the absence of a ferro-magnesian accessory. Calculating all the lime as anorthite, all the soda as albite, and all the potash as orthoclase or microcline, the mineral composition of the aplite and granite becomes:

	Aplite.	Granite.
Potash feldspar	26.69	31.14
Soda-feldspar	38.77	41.95
Lime-feldspar	4.45	2.50
Quartz	28.30	21.09
Excess of Al_2O_3	.61	
Excess of Fe_2O_3	.78	
Excess of FeO		.85
Excess of MgO		.20
Excess of CaO		.67
Excess of H_2O	.21	.70
	99.81	99.10

[1] Analysis *made* in the chemical laboratory of Denison University.

[2] All iron determined as ferric oxide.

In the aplite there is an access of Al_2O_3 after deducting the amount required of the feldspathic constituent of .0059 molecules corresponding by weight to 0.6 per cent., which is probably combined as mica. From the above calculations the ratio of soda feldspar to lime feldspar is 9 : 1 in the case of aplite and 17 : 1 in the case of the granite, corresponding to lime-bearing albite of $Ab_9\ An_1$ and $Ab_{17}An_1$ respectively, when the albite and anorthite molecules are combined to form soda-lime plagioclase. The potash feldspar in both the aplite and granite is part orthoclase and part microcline. According to the calculations the relative abundance of the constituents in the aplite may be expressed as follows: Oligoclase> quartz> orthoclase and microcline> muscovite. In the case of the granite the potash feldspars are slightly in excess of the quartz, otherwise the order of relative abundance of the constituents is the same as for the aplite.

	I.	II.	III.	IV.	V.	VI.
SiO_2	75.07	76.03	76.00	74.21	77.14	74.30
TiO_2	0.09	0.07	0.04	0.30	0.29	none
Al_2O_3	13.07	13.39	14.88	14.47	12.24	14.73
Fe_2O_3	0.61	0.48	0.65	0.35	0.29	0.78
FeO	0.39	0.31	0.10	0.50	1.04	
MnO	trace	trace	trace	none	trace	none
CaO	1.49	1.28	0.19	1.71	0.35	0.90
SrO	0.03	trace	none	trace		none
BaO	0.14	0.04	trace	none		none
MgO	0.14	0.05	0.06	0.28	0.06	strongtrace
K_2O	5.62	5.18	2.77	0.10	4.47	4.52
Na_2O	2.51	2.98	3.52	7.62	4.64	4.61
Li_2O	trace	none	0.20	trace		
H_2O at 100°	0.14	0.15	1.42	0.15	0.14	0.21
H_2O above 100°	0.24	0.34		0.23		
P_2O_5	trace	0.03	0.11	0.07		trace
	100.44	100.33	99.94	99.99	100.66	100.05

I and II. Potash aplites. Described by H. W. Turner, Jour. Geol., 1899, Vol. VII, p. 160; also *Seventeenth Ann. Rept. U. S. Geol. Surv.*, p. 521. W. F. Hillebrand, analyst.

III and IV. Soda aplites. Described by H. W. Turner, Jour. Geol., 1899, Vol. VII, p. 152. III, W. F. Hillebrand, analyst. IV, H. N. Stokes, analyst.

V. Aplite. Described by H. S. Washington, Jour. Geol., 1899, Vol. VII, p. 107. H. S. Washington, analyst.

VI. Aplite. Stone Mountain, Georgia. Thomas L. Watson, analyst.

The percentage ratio of the alkalies in aplites, potash and soda forms a ready basis for grouping them into potash-aplites, soda-aplites, and aplites of equal potash and soda percentages. The Stone Mountain aplite, as shown in the analyses, forms a striking illustration of the third or last type in which the percentage ratio of the potash to soda is equal. To make more emphatic this grouping, and for convenience of comparison, I have tabulated above analyses of some of the recently described well-known aplites from the eastern and western United States:

Tourmaline areas.—A noteworthy feature of the Stone Mountain granite is the somewhat abundant occurrence of small areas of aggregated black tourmaline crystals throughout the entire mass of granite, so far as revealed by quarry operations. Hardly a block of the stone is quarried that does not show a few of these areas. The occurrence of the mineral is not that of a characterizing accessory, as has been noted in some granites, as at Predazzo in the Tyrol, in which the tourmaline takes the place of mica or amphibole, but is more after the order of segregations in the biotite-bearing muscovite granite. Neither are the tourmaline aggregates sufficiently numerous and crowded together in the granite, nor of large enough size, to add to the color of the rock. While clearly visible in every case they do not in any measure detract from the good qualities of the stone for building purposes, for the reasons already stated, and also because of the practical unalterable nature of tourmaline under normal atmospheric conditions.

The tourmaline rarely occurs as isolated or single crystals in the granite proper, but nearly always as radiating and roughly parallel groups, which occupy the centers of perfectly white areas of quartz and feldspar, from which the two micas, muscovite and biotite, have been excluded. The quartz-feldspar areas vary in size from a fraction to several inches in diameter, according to the number of grouped single tourmaline individuals occupying it; and in shape they vary from oblong, irregularly rectangular to complete spherical or circular outlines, with all gradations between. The tourmaline individuals consist of slender prismatic forms, varying from a fraction to several milli-

meters in cross-section without terminal faces; jet-black in color; and in every case examined they are considerably fractured. The number of individuals in a group varies greatly, usually from a half dozen, or thereabouts, to several times that number. The width of the border zone of the feldspar-quartz areas, or that portion of the white mass extending from the outer part of the tourmaline aggregate to the junction formed with the gray granite, is also variable, but is wider in proportion to the size of aggregate occupying the center, and is apparently proportional therefore to the intensity of the action controlling the tourmaline formation.

The quartz-feldspar areas are as strongly contrasted in color with the light gray granite as are the black tourmalines. The junction between the areas and the granite are entirely sharp and distinct, and in no case observed is there any tendency shown toward a gradation or merging of color of the white mass into the granite.

A number of thin sections of the feldspar-quartz areas and their included tourmaline aggregates were examined microscopically. The sections indicated a mosaic of interlocking quartz and feldspar, similar in all respects to, and consisting of the same feldspar species as the granite. No difference in texture and size of the component grains from that of the granite is observed. With few exceptions the feldspars were perfectly fresh. Cataclastic structure is quite strongly accentuated in the feldspar and quartz grains, the cracks are rather wide, and are now filled with a colorless, high double refracting mineral. Primary muscovite is not present in those slides examined, but plentiful small foils of the mineral distributed over the feldspar surfaces are seen in places, and from its association must be regarded as distinctly secondary. In transmitted light the tourmaline is deep brown in color and strongly dichroic. It is closely associated with both the quartz and feldspar, filling at times the interspaces. It is more intimately associated with the feldspar, however, and its distribution through some of the large microcline and oligoclase individuals as partially connecting irregular and ragged granules closely resembles the poikilitic

structure. In some cases the tourmaline is entirely confined to the feldspar individual, while in others it cuts well into the quartz and feldspar grains in such way as to clearly indicate its subsequent formation. In cross-section the mineral appears in some cases to be irregularly rounded and granular rather than bounded by sharp crystalline boundaries, but most of it is so very irregular that it is best described as having an exceedingly ragged outline. In a few instances the prism faces are indicated under the microscope. The mode of occurrence of the tourmaline and its association with the feldspar suggests beyond reasonable doubt its derivation in part from the feldspar, by fumarolic action.

The tourmaline cannot be regarded as a product of contact phenomena, since it is generally distributed throughout the entire mass of granite, so far as quarrying operations extend—not more abundant at one point than at another. I have elsewhere shown[1] that the present granite ridge, Stone Mountain, is the unreduced remnant or "core" of a once more extensive mass. The evidence favoring this is that, on the north, west, and south sides of the ridge, a belt of the same granite, reduced to the same general level of the surrounding Tertiary Piedmont plain, skirts the ridge for a distance varying from a quarter to more than a mile in width. In this reduced granite zone numerous quarries have been worked yielding the same beautiful light gray nearly white Stone Mountain granite. The rock quarried in this zone is strikingly free from the tourmaline aggregates, less than a half dozen in all having been observed. The areas, then, are confined to the ridge portion of the granite mass, and do not characterize the border portions of the granite nor of the adjoining schist and gneiss where exposed.

Black tourmaline as isolated single crystals and aggregates is rather a common associate in the Stone Mountain pegmatites, and in several instances veinlets of twelve and more inches long of tourmaline-felt (fine acicular tourmaline), as much as an eighth of an inch in width, have been noted in the granite in

[1] *A Report on the Granites and Gneisses of Georgia, Geological Survey of Georgia.* In press.

the northwest quarries of the ridge. While no distinct evidence bearing on the contemporaneous origin of the tourmaline aggregates in the granite with those of the pegmatite and the tourmaline veinlets, it seems reasonable to assume such contemporaneity.

The very nature of the areas oppose the hypothesis of direct secretion out of the eruptive granite magma. On the other hand, the characteristic mode of occurrence and intimate relationship to certain other mineral species present, as shown both macroscopically and microscopically, make it reasonably certain that the tourmaline areas have resulted from fumaroles highly charged with boric acid acting on the feldspars and mica.

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ON THE OCCURRENCE OF URANOPHANE IN GEORGIA.[1]

By Thomas L. Watson.

The object of this paper is to describe the occurrence of the rare mineral uranophane from a new locality. State Geologist Yeates first observed the occurrence of the yellow mineral at Stone Mountain, Georgia, in the early nineties and later had Mr. R. L. Packard examine the material chemically in the laboratory of the Georgia Survey. During 1898 and 1899, while engaged in a field study of the Georgia granites, the writer independently noted the occurrence of this mineral at the same locality, as a thin, yellow incrustation coating the faces of many of the joint planes cutting the Stone Mountain granite mass. Specimens were carefully collected and studied in the laboratory of the Survey in Atlanta.

So far as the writer can ascertain, uranophane is reported from only one locality in the United States, namely, Mitchell county, North Carolina.[2] Here the mineral is found incrusting and penetrating gummite as an alteration product at the mica mines. Under the title "On Some New Mineral Occurrences in Canada," G. Chr. Hoffman[3] of the Canadian Geological Survey has recently described the occurrence of uranophane from Ottawa county, Quebec. According to Hoffman, the mineral in Quebec is associated with "gummite, uraninite, black tourmaline, white, light gray, pale olive-green and bluish green apatite, spessartite, monazite, and green and purple fluorite, in a coarse pegmatite vein composed of white and light to dark, smoky-brown quartz, microcline and muscovite, which traverses a gray garnetiferous gneiss." The mineral is further

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[1] Reprinted from the American Journal of Science, fourth series, Vol. XIII, pp. 464–466, 1902.

[2] Dana, E. S., A System of Mineralogy, 1893, p. 699.

[3] Am. Jour. Sci., **11**, pp. 152–153, 1901.

described as an alteration product of gummite, occurring "in small bright lemon-yellow fibrous masses, sometimes in immediate contact with the gummite found coating the uraninite or, *per se*, embedded in the albite immediately surrounding the tourmaline and often invading the latter." In both Quebec and North Carolina the mineral is an alteration product of gummite, and, in this particular, its occurrence is similar for the two localities, while in Georgia the occurrence is entirely different, as will be noted in the following description.

At Stone Mountain, Georgia, sixteen miles east of Atlanta, the mineral uranophane is found as a distinct incrustation, coating the faces of many of the joint planes, which cut the granite boss. It varies from a sulphur-yellow to lemon-yellow in color, the former predominating, and forms an irregular coating not exceeding one-eighth to one-sixteenth of an inch in thickness, usually less. It is tipped or coated with the clear, colorless, and transparent, drop-like forms of the mineral hyalite. The two minerals are so intimately associated that it is almost impossible to effect a complete separation of them.

The Stone Mountain granite, with which the uranophane is associated, is a light gray, medium-grained, biotite-bearing muscovite granite, composed of quartz, orthoclase, microcline and soda-lime (oligoclase) feldspar, muscovite and biotite, with sporadic microscopic accessories. Fresh specimens of the granite were analyzed by Packard in the Survey laboratory with the following results:

SiO_2	72.56
Al_2O_3	14.81
FeO	0.84
CaO	1.19
MgO	0.20
Na_2O	4.94
K_2O	5.30
H_2O (ignition)	0.70
Total	100.4

Several tests were made by the writer on separate portions of the granite for the presence of uranium, with negative results. The yellow powder gave the usual tests before the blowpipe for uranophane. Packard carefully separated, by means of

a lens, a small amount of the yellow mineral from particles of the granite and other possible impurities for chemical analysis. 0.1310 gram of the powder was used, which gave:

SiO_2	18.55
$U(UO_4)_2$	47.18
$(UO_2)_2$, Fe_2O_3, P_2O_5	4.95
Al_2O_3	6.33
CaO	6.64
MgO	1.98
H_2O (ignition)	13.28
Total	98.91

As Packard remarks, the above result clearly indicates that the material was not entirely free from impurities. A second weighed portion was accordingly selected amounting to 0.5120 gram of the dull lemon- or sulphur-yellow mineral and treated with HNO_3, which after digestion left a residue weighing 0.2460 gram, yielding 0.2660 gram for analysis. This gave: $U(UO_4)_2$ 61.28, corresponding to 60.14 per cent of UO_2; CaO 6.01.

Accepting then the percentages of SiO_2 and H_2O in the first analysis, and those of UO_3 and CaO in the last, as representing the composition of the mineral; and disregarding the percentages of Fe_2O_3, Al_2O_3, MgO and P_2O_5, and recalculating the four essential oxides to a basis of 100, the ratios become:

	I.	II.	III		
CaO	6.01	6.14	.109	=	1
UO^3	60.14	61.37	.213	=	1.95
SiO^2	18.55	18.93	.315	=	2.88
H^2O	13.28	13.56	.753	=	6.90
	97.98	100			

I. Analysis of uranophane from Stone Mountain, Georgia, from which the small percentages of Al_2O_3, Fe_2O_3, MgO and P_2O_5 are omitted.

II. Analysis I recalculated to a basis of 100.

III. Molecular ratios of II.

The molecular proportions given under column III correspond to the formula $CaO.2UO_3.3SiO_2 + 7H_2O$, which indicates one part more of SiO_2 and H_2O than is required by the formula for uranophane, $CaO.2UO_3.2SiO_2 + 6H_2O$. The dis-

crepancy in these two constituents is easily accounted for, however. The SiO^2 is increased by the presence of finely divided mineral particles from the granite and hyalite, it being quite impossible to effect a complete separation of the uranophane from these two. The amount of available material was so small that it was impossible to separately determine the combined and uncombined water, and under the total water given in the analysis, it is reasonable, at least, to assume that a small fraction of it is hygroscopic (uncombined) water. What now appears then as a slight variation from the exact formula for uranophane, disappears when the above facts are considered.

A comparison of the above analysis of the Georgia mineral with several by Genth and von Foullon of the uranophane from Mitchell County, North Carolina, and one from Kupferberg, Silesia, quoted by Dana,[1] shows very close agreement. The reported occurrence of uranophane in granite at Kupferberg in Silesia appears in this particular to be similar to that in Georgia.

Geological Laboratory of Denison University,
Granville, Ohio.

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[1]Op. cit.

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A DEFORMED CHICK.

With Plates VI.

By LYNDON M. HILL

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Granville, Ohio, October, 1902.

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Bulletin of the Scientific Laboratories of Denison University.

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A DEFORMED CHICK.

By Lyndon M. Hill.

John M. Sontag has said that chicks hatched under a hen are never deformed. Last fall I received a chick, which had been hatched out of barred Plymouth rock eggs, by a barred Plymouth hen.

This chick was deformed and the deformity was pronounced enough to attract attention. At birth the chick was as vigorous as any in the brood; but the deformity was a handicap to the chick and in a few days the struggle with the other normal chicks ended in death by starvation.

To the casual observer one of the chick's legs was much shorter than the other; to the naturalist the leg was not only shorter than usual, but it contained only three toes and two of those were webbed from the proximal end to the nails. It was this peculiar modification which led me to think the chick was worth a careful study.

In the following tables an attempt is made to contrast the normal and abnormal legs; not only as to external morphology but also as to their skeletons.

TABLE A.

Normal Leg	Length	Greatest diameter at middle	Least diameter at middle	Greatest diameter at proximal end	Least diameter at proximal end	Greatest diameter at distal end	Least diameter at distal end	Remarks
Bone 1	20 mm.	2 mm.	2 mm.	3.80 mm.	2.58 mm.	4.505 mm.	3.08 mm.	Curved bone
Bone 2	30 mm.	1.76 mm.	1.76 mm.	5.29 mm.	3 95 mm.	4.83 mm.	3.79 mm.	
Bone 3	16 mm.	2.77 mm.	1.51 mm.	4.82½ mm.	3 33 mm.	5.16 mm.	2.90 mm.	
Abnormal Leg								
Bone 1a	18 mm.	1.66½ mm.	1.66½ mm.	3.35 mm.	2.17 mm.	3.33½ mm.	2.82 mm.	
Bone 2a	17 mm.	1.68 mm.	1.53 mm.	3.73½ mm.	2.95½ mm.	3.17 mm.	2.70½ mm.	
Bone 3a	9 mm.	3.97½ mm.	1.07 mm.	3.93½ mm.	1.68½ mm.	4.93 mm.	1.95 mm.	The bone is Y-shaped, open at the distal end

TABLE B.

Normal Leg	Bone	Length	Remarks
Toe 1	1	4.48 mm.	
	2	2.86 mm.	
	3	2.43 mm.	
	4	2.58½ mm.	
	N	2.92 mm.	
Toe 2	1	6.2 mm.	
	2	4.76½ mm.	
	3	4.72 mm.	
	N	5.30 mm.	
Toe 3	1	6.46 mm.	
	2	4.38 mm.	
	3		
	N	4.11 mm.	
Toe 4	1	2.38½ mm.	
	2	4.57 mm.	
	3		
	N	3.39 mm.	

TABLE C.

Abnormal Leg	Bone	Length	Remarks
Toe 1	1	5.15 mm.	
	2	4.15 mm.	
	3	4.14 mm.	
	4		
	N	5.16½ mm.	
Toe 2	1	3.85 mm.	
	2	2.65 mm.	
	3	2.96 mm.	
	N	4.40 mm.	
Toe 3	1	3.40 mm	Cartilage
	2	4.87 mm.	
	3		
	N	3.65 mm.	
Toe 4	1		Missing
	2		Missing
	3		Missing
	N		Missing

The structural differences between these legs are contrasted in figs. 1, 2, 3, 4, 5 and 6. The abnormal leg has only three toes and no trace of a fourth. The normal leg has four toes.

The table given above renders a detailed description unnecessary. I must mention however that in the abnormal leg the first and second bones of the third toe have fused, and that the femur of the abnormal leg contains a conspicous spine for the insertions of muscles and that the nails of the abnormal leg are relatively larger than those of the other leg.

The resemblance of this deformed leg to the normal leg of the auk is both astonishing and instructive. The following table diplays that comparision.

THE DIVING BIRDS.—THE AUKS.	DEFORMED CHICK.
Characteristics.	*Characteristics.*
1. Backward position of their legs.	1. Backward position of the deformed leg.
2. The toes are either webbed or lobed.	2. The toes of the deformed leg are webbed.
3. The absence of one toe.	3. The absence of one toe.
4. The tibia relatively short.	4. The tibia relatively short, compared with the tibia of the normal leg.
5. The toes have claw-like nails.	5. Have claw-like nails.

In drawing inferences concerning deformities one must not jump to hasty conclusions. That this deformed leg resembles the normal legs of the diving birds there can be no doubt and to the writer this seems to be an unilateral reversion. Even though this conclusion should not stand the test of time, it is thought that the above description of the facts in the case will be of value to students of variations.

BIOLOGICAL LABORATORY OF CLARK UNIVERSITY,
SO. ATLANTA, GA.

EXPLANATION OF PLATE.

Fig. 1. Deformed Chick—Lateral View.
Fig. 2. Deformed Chick—Dorsal View.
Fig. 3. Deformed Leg.
Fig. 4. Normal Leg.
In 3 and 4 the dotted lines indicate the position of the leg bones.
Fig. 5. Skeleton of the Deformed Leg.
1 a=Femur, 2 a=Tibia, 3 a=Cannon Bone.
1 to 3=phalanges. N=Nail.
Fig. 6. Skeleton of the Normal Leg.
Bones are numbered as in fig. 5.
Figs. 3 to 6 were drawn with a camera.

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A NOTE ON THE SIGNIFICANCE OF THE SIZE OF THE NERVE FIBERS IN FISHES.

By C. JUDSON HERRICK

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A NOTE ON THE SIGNIFICANCE OF THE SIZE OF NERVE FIBERS IN FISHES.[1]

By C. Judson Herrick.

The observations upon the relation between diameter and distribution of nerve fibers in the frog, reported upon by Miss Dunn ('02), call to mind certain facts which came under my notice in the prosecution of my researches on the nerve components of fishes and which may serve to supplement as well as to verify her observations.

The eye-muscle nerves of Menidia I have found (see Section 9 of the work cited in the appended bibliography) to contain both typical coarse motor fibers and also very fine fibers which leave the brain bound up in the same root with the others, but terminate peripherally on a different set of muscle fibers. All of the extrinsic eye-muscles have, in addition to the usual large muscle fibers, a large number of very small ones. These latter are, for the most part, segregated into a separate slip, which may have a slightly different origin from the main muscular mass. The finer nerve fibers can be separately followed from the superficial origin of the nerve to their insertion in the muscle and the separation of the finer muscle fibers from the coarse ones makes it easy to determine the exact distribution of the two kinds of nerve fibers. To quote from the work just cited (p. 389), "In the case of each of the six eye-muscles of which we have just been treating, the side along which the finer fibers of its nerve run contains much smaller muscle fibers than those which make up the body of the muscle, the diameter of these small muscle fibers often being no greater than that of a large nerve fiber. The smaller

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[1]Studies from the Neurological Laboratory of Denison University, No. XVI.

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muscle fibers are not merely the ends of larger ones which have become attenuated near their insertion, but they run for nearly the whole length of the muscle, maintaining the same diameter and the same relation to the larger ones. They do not appear to differ from the ordinary fibers except in size, in their constant relation to the finer nerve fibers and particularly in the fact that they are in places more closely enveloped by a dense and very rich plexus of these finer nerve fibers and by a nucleated connective tissue interstitial substance."

The point in this description to which I here direct attention is the fact that the large and small nerve fibers leave the brain together and are apparently approximately equal in length. In fact, the smaller fibers in general may be a trifle longer, for they usually end farther out on the muscle towards its insertion than do the larger ones. The size of the nerve fibers is evidently correlated with the size of the muscle fibers to be innervated. I have verified this observation on several other bony fishes; viz., the cod, the gold fish and the cat fish, whose eye-muscles show the same peculiarity of innervation.

In Section 5 of the same memoir is described a similar condition in connection with certain muscles (presumably all of the visceral type) about the beginning of the oesophagus of Menidia. On page 264 the description of the innervation of the m. pharyngeus transversus is as follows: "This is a large stout muscle extending between the two inferior pharyngeal bones. It is incompletely divided into two parts, a large ventral part which is supplied by a small number of very coarse and heavily myelinated fibers, like those for the other branchial muscles which can be traced back into the common motor component [of the vagus nerve], and a smaller dorsal part which is dorsally confluent with the general constrictor muscles of the oesophagus and like them is supplied by many very fine fibers whose origin could not be traced. The muscular fibers of the ventral part are very large and thick, those of the dorsal part smaller, but not so small as those of the proper constrictor of the oesophagus." Here again we have a case where nerve fibers of the same length and type (both viscero-motor) differ

conspicuously in diameter and this is correlated with a similar difference in the size of the muscle fibers innervated.

I have observed many similar cases, especially among the branchial muscles of fishes, whose fibers vary greatly in size, depending apparently upon the functional importance of the muscle in question. It is a general rule, though by no means an invariable one, that in the fishes large muscle fibers are supplied by large nerve fibers and conversely small muscle fibers by small nerve fibers, irrespective of the relative length of the nerve fibers.

Now, to return to Miss DUNN'S paper, she finds that SCHWALBE'S inference, that, other things being equal, the longest nerve fibers have the largest diameter, does not hold true in the case of the sciatic nerve of the frog. On the other hand, the largest nerve fibers, it appears from her observations, are given off with the branches for the thigh, while the shank and foot are innervated by the smaller fibers.

Now, if we confine our attention for the moment to the motor fibers of the sciatic nerve, those for the muscles of the thigh should be larger in diameter than those for the shank, provided our rule stated above holds true, since the muscles of the thigh are much larger and more important, functionally, than those of the shank.

But this peculiarity is not confined to motor fibers. In the study of the innervation of the cutaneous sense organs of fishes I have met with many analogous instances. Thus, the organs of the lateral line system of fishes are usually innervated by very large nerve fibers, the largest in the body. But in many fishes a part of the organs of this system are greatly reduced in size, and presumably in functional importance. That these reduced organs are of small functional importance is rendered still more probable by the fact that their essential sensory cells, the hair cells, exhibit a greater proportional reduction than the indifferent supporting cells. Now, these reduced organs, irrespective of their position on the body and hence of the length of the nerve fibers which innervate them,

are as a rule supplied by much smaller nerve fibers than are the large and highly functional organs of the same fish.

Still another case is furnished by the terminal buds (gustatory organs) of the outer skin and barblets of some fishes. The distribution and innervation of these organs I have worked out in some detail in the case of Ameiurus melas, as already reported (Herrick, '01). These organs are similar in structure to the taste buds in the mouth and like them they are innervated by communis nerves, so that the nerves of the two sets of sense organs can be directly compared. It is characteristic of communis nerves generally that their diameter is less than that of other types of cerebro-spinal nerves and the medullary sheaths are thin. The communis nerves which supply the taste buds of the mouth cavity are not exceptions to this rule, but those which supply the very large gustatory organs of the outer skin of the siluroids are considerably larger and are provided with much more dense medullary sheaths than is usual for fibers belonging to this system. The more highly developed terminal organs and greater functional importance doubtless have called forth a change in the character of the nerve fibers. That these cutaneous sense organs of the siluroid fishes are in fact highly functional as a gustatory apparatus I can definitely affirm on the basis of experiments now nearly ready for publication.

Miss Dunn concludes that in the case which she has examined there is no direct correlation between the diameter of the nerve fibers and the length of the fibers. I would make this conclusion general and add to it that there is, in some cases at least, a correlation between the diameter of the fiber and the functional importance of the fiber, or the physiological importance of its terminal organ as compared with other organs of the same system. The qualification stated, "of the same system," is important. In 1899 I formulated (p. 173 of the Menidia paper) the following definition of the functional system of nerves: "Each system may be defined as the sum of all fibers in the body which possess certain physiological and morphological characters in common, so that they may react in

a common mode. Morphologically, each system is defined by the terminal relations of its fibers—by the organs to which they are related peripherally and by the centers in which the fibers arise or terminate." It so happens that throughout the vertebrate series the peripheral fibers of each system have certain tolerably uniform characteristics of caliber, medullation, etc., by which they may be distinguished from those of other systems. This fact lies at the basis of much of the recent work on nerve components, in the course of which the several systems of components have been followed through serial sections from their primary centers within the brain to their peripheral termini. These fiber characteristics are, however, by no means inflexibly fixed, but, as we have seen above, are sometimes subject to wide and very confusing variations, partly explicable as functional adaptations, partly as yet unexplained.

These variations oppose very grave obstacles to the determination of the morphological rank of any organs on the basis merely of the size of the nerve fibers innervating them. For instance, the division of the body musculature into somatic and visceral systems needs a much more secure foundation than that afforded by studies on the caliber of the nerve fibers supplying the several muscles such as have been made by GASKELL, SHORE, EDGEWORTH and others. This character is doubtless an important aid, but it requires rigid embryological control. This is clearly appreciated by some of these authors, who have followed their measurements of nerve fibers by an embryological study of the muscles innervated.

By way of summary, then, we conclude that each functional system of peripheral nerves has tolerably definite fiber characteristics, the basis for which is as yet unknown; that these characteristics are by no means invariable, but that the fibers of a given system may show considerable differences in caliber and medullation in a single animal; and that some of these differences, at least, may be correlated with the degree of functional development of the peripheral end-organ. In general, highly developed muscle fibers, sense organs, etc. receive larger

nerve fibers than similar organs in a state of structural and functional degradation.

LITERATURE CITED.

1902. Dunn, Elizabeth H. On the Number and on the Relation between Diameter and Distribution of the Nerve Fibers Innervating the Leg of the Frog, Rana virescens brachycephala, Cope. *Journ. Comp. Neurol.*, XII, 4. 1902.

1899. Edgeworth, F. H. On the medullated fibers of some of the Cranial Nerves, and the development of certain Muscles of the Head. *Journ. Anat. and Physiol.*, XXXIV, pp. 113-150.

1886. Gaskell, W. H. On the Structure, Distribution and Function of the Nerves which Innervate the Visceral and Vascular Systems. *Journ. of Physiol.*, VII.

1889. Gaskell, W. H. On the Relation between the Structure, Function, Distribution and Origin of the Cranial Nerves, together with a Theory of the Origin of the Nervous System of Vertebrata. *Journ. of Physiol.*, X.

1899. Herrick, C. Judson. The Cranial and First Spinal Nerves of Menidia; A Contribution upon the Nerve Components of the Bony Fishes. *Journ. Comp. Neurol.*, IX, 3-4.

1901. Herrick, C. Judson. The Cranial Nerves and Cutaneous Sense Organs of the North American Siluroid Fishes. *Journ. Comp. Neurol.*, XI, 3.

1882. Schwalbe, G. Ueber die Kaliberverhältnisse der Nervenfasern. *Leipzig.*

1888. Shore, Thos. W. The Morphology of the Vagus Nerve. *Journ. Anat. and Physiol.*, XIII.

1889. Shore, Thos. W. On the Minute Anatomy of the Vagus Nerve in Selachians, with Remarks on the Segmental Value of the Cranial Nerves. *Journ. Anat. and Physiol.*, XXIII.

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THE ORGAN AND SENSE OF TASTE IN FISHES.

By C. JUDSON HERRICK

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THE ORGAN AND SENSE OF TASTE IN FISHES.

By C. Judson Herrick,
Professor of Zoology in Denison University.

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INTRODUCTION.

The practical problems connected with the fisheries have been attacked (and in a large measure successfully solved) by a rough-and-ready application of the method of trial and error, and the scientific investigator has merely to follow after and explain why a given form of trap or method of lure is successful with one species of fish and not with another. But there remain many unsolved problems of great economic importance and it is the function of scientific research to contribute to the solution of these problems in a more orderly and economical manner, even though it often happens that the investigator best qualified to solve the scientific problem has not the practical knowledge of fishery matters necessary to apply his own results to economic problems, and so his facts have to be worked over from the other point of view before they become practically useful.

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We are, in fact, profoundly ignorant of the senses and instincts of the fishes, even those connected with their feeding habits which are of so direct importance to all commercial fisheries. Nearly all which one finds in the scientific literature bearing on the senses of fishes is merely inference of function based on a study of the structure of the organs—a most precarious pathway for scientific research. My own studies on the nerve components of fishes have led me to certain inferences regarding the function and distribution of the organs of taste in fishes, and the present study is an attempt to follow out these inferences by the determination of more exact facts regarding the pathways of gustatory stimuli as anatomically demonstrable, together with sufficient direct physiological experiment to furnish definite information of the function served by this system of sense organs and of their nervous paths in the fishes.

Neurologists have always paid a great deal of attention to the conduction paths within the central nervous system, and in recent years special efforts have been made to isolate the various functional systems of neurones, tracing the exact path of the sensory impulses from the peripheral organ to the primary sensory center, thence to the various secondary centers and return reflex paths. This motive underlies the recent studies on the nerve components, and indeed much of the best morphological work on the nervous system in all times. Some years ago I formulated the following definition of such a functional system of neurones, with special reference to the peripheral members of the system: "The sum of all the nerve fibers in the body which possess certain physiological and morphological characters in common so that they may react in a common mode. Morphologically each system is defined by the terminal relations of its fibers—by the organs to which they are related peripherally and by the centers in which the fibers arise or terminate. The fibers of a single system may appear in a large number of nerves repeated more or less uniformly in a metameric way (as in the general cutaneous system of the spinal nerves), or they may all be concentrated into a single nerve (as in the optic nerve)." Now if we add to this the secondary paths re-

lated to the primary central end-stations, referred to above, and the chief reflex arcs directly associated therewith, we shall have a picture of the system in its entirety.

The functional system with which we are especially concerned in the present research is that known to comparative anatomy as the communis system, including (1) unspecialized visceral sensory fibers ending free in the mucous surfaces of various viscera without special sense organs—probably phylogenetically the more primitive elements—and (2) specialized sensory fibers always ending in connection with highly differentiated sense organs in the mouth, pharynx, lips or outer skin, known as taste buds, terminal buds or end buds, and in general serving the function of taste. These specialized elements are probably of more recent phylogenetic origin than the first group and the term gustatory system will be used to designate these organs, wherever placed on the body surface, together with their nervous pathways toward and within the brain. In other words, the gustatory system is that portion of the communis system of neurones which serves the sense of taste, as distinguished from those communis neurones which serve less highly specialized visceral sensations.

These two groups of fibers can easily be distinguished peripherally of the brain, but centrally they have not as yet been successfully analyzed. Hence in treating of the central gustatory path we cannot be sure that we do not include the unspecialized visceral system also. But since in some fishes the gustatory fibers preponderate many fold over the unspecialized fibers of the communis system, there is no ambiguity arising from this central confusion of the two elements so far as the gustatory system is concerned, since the secondary paths as clearly traceable in these fishes must be made up chiefly of gustatory fibers.

The central gustatory path is not definitely known either in man or in any other vertebrate, so far as shown by the available literature; I have therefore studied with some care the brains of some fishes in which this system is enormously developed in the hope that they would throw light on this unsolved

problem of vertebrate anatomy. And in this I have not been disappointed, though my study of the central paths is not yet sufficiently advanced for publication.

As intimated above, sense organs belonging to the communis system and presumably serving the function of taste are found in the mouth of all fishes ("taste buds"). They are frequently found upon the lips, and in some cases they are found likewise plentifully distributed over extensive areas of the outer skin of the head and trunk. In this latter case they are commonly termed terminal buds or end-buds (*Endknospen*, *Becherorgane*, of the Germans). They must in all cases be sharply distinguished from the neuromasts, or organs of the lateral line system (German, *Nervenhügel*), though these latter occur in the skin of fishes in a great variety of forms, often resembling the terminal buds very closely. The innervation and functions of the two systems of organs are, however, wholly different, and they really have nothing to do with each other. I shall illustrate more fully in a later section of this paper the structure of the terminal buds and the details of their innervation; I here call attention merely to the important fact that both in structure and in nerve supply they resemble most closely the taste buds of the mouth. From this one naturally infers for them a gustatory function. Since, however, inferences are not in order when facts are available, I have undertaken to determine experimentally the function of these cutaneous sense organs of the communis system.

The experiments which I have made are of an exceedingly simple nature, the attempt being to put the fish while under observation in as nearly normal conditions as possible and to utilize the ordinary feeding and other instinctive reactions so far as possible in the accumulation of the data. These are the methods of the old-time observational natural history, it is true, as contrasted with the methods of precision of the modern physiological laboratory. They have, however, proven sufficient for their purpose, which was merely to determine the class of stimuli to which the terminal buds are sensitive, or the sensational

modality which they serve, rather than to contribute to the chemical physiology of taste in general.

The chief obstacle to experiments of this sort, and one which many observers seem to have made no serious efforts to overcome, is the natural timidity or shyness of wild creatures when kept in the confined and unnatural quarters necessary for close observation. The rôle played by fear in animal behavior has been vividly brought to our notice by Whitman ('99), and, like this observer, I find that young animals which have been reared in captivity are much more approachable and tractable under experimental conditions than adults which have been reared in their natural freedom. In fact, with several species I quite failed to get the adults to take food at all in captivity, though they were under observation for long periods.

SECTION I. REVIEW OF LITERATURE.

Surprisingly little attention has been paid to the physiology of taste in fishes and this literature is very scanty. On the other hand, the anatomical investigation of these sense organs has been extensively followed for nearly a century, though often in a blind and profitless way. The history of opinion upon the significance of these sense organs has been quite fully given by Merkel ('80) in his great monograph published in 1880, and the earlier phases of this history need not be again reviewed further than to mention a few salient features.

In 1827 Weber observed the taste buds on the peculiar palatal organ of the carp and correctly interpreted their function. He also figured the brain of the carp, illustrating the enormous vagal lobes from which these taste buds receive their innervation. Leydig discovered in 1851 the terminal buds of the outer skin of fishes and gave a detailed account of their structure which subsequent research has shown to be in some respects inaccurate. In 1863 F. E. Schulze gave a more accurate description of the "becherförmigen Organe" of fishes, in which he distinguished the specific sensory cells from the supporting cells. He also correctly inferred their function to be similar to

that of taste buds within the mouth, viz., the perception of chemical stimuli.

In 1870 the same author (F. E. Schulze, '70) made a further important contribution to the problem of the terminal buds by the demonstration that they differ structurally from all neuromasts, or organs of the lateral line system. The neuromasts are commonly sunken below the skin in canals, tubes or pits, but in some cases they are strictly superficial and resemble in external form the terminal buds very closely, a feature which led Leydig ('51, '79, '94) and others to assume that the two classes of organs are mere varieties of a common type. Schulze showed that the neuromasts can in all cases be differentiated from the terminal buds by the fact that their specific sensory cells (pear cells) extend only part way through the sensory epithelium and fail to reach the internal limiting membrane, while in the terminal buds both specific sensory cells and supporting cells pass through from external to internal limiting membrane.

This distinction was confirmed by Merkel ('80) who, with curious inconsistency, while recognizing the structural dissimilarity of the two classes of organs, nevertheless, as we shall see below, ascribes to both essentially the same function, touch. This matter was put to the decisive test in my contribution on *Ameiurus* ('01), a type which possesses both terminal buds and neuromasts in great abundance and diversity of forms. Schulze's contention is supported both by the structure of the organs and by their innervation; for I have shown that all neuromasts, of whatever form, are innervated by acustico-lateralis nerves from the tuberculum acusticum of the brain, while all terminal buds, whether within the mouth or in the outer skin, are innervated by communis nerves related centrally to a single center within the brain. This center is bi-lobed, the lobus vagi receiving most of the communis fibers from the mouth cavity by way of the vagus and glossopharyngeus and the lobus facialis the communis fibers from the terminal buds of the outer skin by way of the facial nerve (cf. Fig. 1).

Similar terminal buds have been found in the outer skin of many species of Teleostomes and in Cyclostomes, but, so far as certainly known, nowhere else among vertebrates (save on the lips of some other classes). Their distribution among the fishes

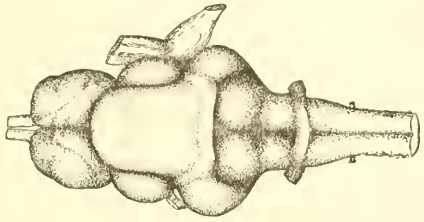

Fig. 1. Dorsal view of the brain of the adult yellow cat fish (Leptops olivaris Raf.). The olfactory bulbs with most of their crura have been removed; also the membranous roof of the fourth ventricle, exposing the facial and vagal lobes. This ventricle is bounded behind by a transverse ridge containing the commissura infima Halleri and the commissural nucleus of Cajal. The posterior pair of tuberosities, next to the commissure, are the vagal lobes; the anterior pair, next to the cerebellum, are the facial lobes. × 2.

is very irregular, being most abundant among the siluroids, cyprinoids, ganoids and cyclostomes, in general bottom fishes of sluggish habit, often living in mud and rarely belonging to the predacious types which find their food chiefly by the sense of sight. The following list of fishes which have been shown to possess terminal buds on the outer skin is by no means complete, but will serve to illustrate the wide range of species which have acquired this peculiarity:

FISHES POSSESSING TERMINAL BUDS ON THE OUTER SKIN.

Acerina. On fins and body (Merkel, '80).

Acipenser sturio, sturgeon. On barbel (Merkel, '80). Also other sturgeons.

Agonus cataphractus, pogge. On the villiform tentacles beneath the head (Bateson, '90).

Ameiurus melas, cat fish, and other North American Siluridae. On barblets and nearly the whole body surface (Herrick, '01).

Amia calva, bowfin. On skin of head and other parts (Allis, '97).

Anguilla vulgaris, eel. On the fins, lips and anterior nostril (Merkel, '80; Bateson, '90).

Aspius alburnus. (Merkel, '80.).

Barbus fluviatilis. On barblet (F. E. Schulze, '63).

Branchiostoma lanceolatum=Amphioxus lanceolatus, lancelet. On the oral cirri (Merkel, '80).

Carassius auratus, gold fish. On whole body (numerous authors; Herrick).

Cephalacanthus=Cobitis fossilis, flying gurnard. (Merkel, '80).

Cottus scorpius. On fins (Merkel, '80).

Cynoscion=Corvina. (Merkel, '80).

Cyprinus carpio, carp, and other cyprinoids. On whole body (Merkel, '80, and others).

Dactylopterus. (Merkel, '80).

Discognathus lamta, Indian carp. Over the whole body surface (Leydig, '94).

Enchelyopus=Motella, four-bearded rocklings. On barblets and pelvic fins (Bateson, '90).

Gadus callarias, cod. On lips, barbel, fins and body (Merkel, '80; Herrick, '00).

Gadus luscus, pouting. On the lips, barblet and pelvic fins (Bateson, '90).

Gadus merlangus. whiting. On the lips (Bateson, '90).

Gadus pollachius, Pollack. On the lips (Bateson, '90).

Gaidropsarus=Motella, three-bearded rockling. On all the barblets and pelvic fins (Zincone, '78; Bateson, '90).

Gobius, goby. On fins (Merkel, '80).

Hippocampus, sea horse. (Merkel, '80).

Leptocephalus conger, conger eel. On the outer and inner lips (Bateson, '90).

Leucaspius delineatus. On the body generally (Leydig, '94)

Leuciscus dobula. (Leydig, '57).

Lota vulgaris. On barblet (Merkel, '80).

Mullus barbatus, mullet. On barblet (Zincone, '78; (Merkel, '80).

Petromyzon fluviatilis, lamprey. On skin of whole body (Merkel, '80, and others).

Pygosteus=Gasterosteus pungitius, stickleback. Merkel, '80).

Rhodeus amarus. On the body generally (Leydig, '94).

Scorpaena. (Merkel, '80).

Silurus glanis. (Merkel, '80).

Solea vulgaris, sole. "Contrary to the natural presumption, the villi on the lower (left) side of the head do *not* bear sense organs, though, as Mr. Cunningham informs me, such organs are found between the villi" (Bateson, '90).

Tincta vulgaris. On barblet (Merkel, '80).

As already suggested, our knowledge of the functions of all of the sense organs of fishes is very imperfect, since speculation based upon structure has seemed more attractive to most authors than accurate physiological research. The monograph of Merkel ('80) with its great wealth of accurate anatomical data on the structure and distribution of terminal buds in all classes of vertebrates, gives an excellent illustration of the dangers in the path of even so skillful an observer when he goes beyond the bounds of observed fact and enters the field of speculation. This author recognizes the close structural resemblance between these organs and the undoubted organs of taste in the human body. He controverts, however, the clear argument of F. E. Schulze for their gustatory function on merely theoretical grounds. His first objection is based on their innervation. Instead of being supplied by a single gustatory nerve, the glossopharyngeus, they may be supplied, he says, by any other body nerve. This objection has been totally removed by the discovery (compare especially my own Ameiurus paper, already referred to, published in October, 1901) that all terminal buds, no matter where located on the body and no matter from what nerve branches their innervation seems to come, are in reality supplied by nerves of a single physiological system, terminating in the brain in a single center—the communis nerves.

Again, he objects to Schulze's theory that the terminal buds serve to localize gustatory stimuli on the various parts of the body, on the ground that an organ of chemical sense stimulated by substances in solution in the environing fluid could not receive a sufficiently circumscribed stimulation. It is unnecessary to follow the argument in detail, for the experiments which I shall describe shortly show conclusively that when the sapid substance is brought into contact with these organs or very

near to them, the stimulus is accurately and very promptly localized, and in fact some of the fishes studied habitually find their food by this very power, the gustatory stimulus calling forth an immediate reflex movement toward the point stimulated. It is probable that the local sign is not given by the gustatory (communis) nerves, but by the accompanying tactile (general cutaneous) nerves of the corresponding cutaneous area (which general cutaneous nerves Merkel curiously enough denies to the fishes altogether, whereas in fact they are plentifully supplied to all parts of the skin), though my experiments do not decisively answer this question. Weak stimuli, especially when uniformly diffused through the water are, it is true, not at all localized; but strong stimuli are unquestionably localized by one method or another.

In fact, Merkel agrees with Jobert that the terminal buds of the outer skin are tactile in function. This is based largely on the erroneous belief, referred to above, that there are no free tactile nerve endings in the skin of fishes, and also on the observed tactile sensibility of the barblets and other parts of the body known to be most plentifully supplied with terminal buds. But I have shown that all of these parts of the body receive, in addition to communis nerves for the specialized sense organs, a most liberal cutaneous innervation for tactile sensibility; and the experiments which follow go to show practically that these two functions commonly co-operate in setting off the reflex of seizing food, though they may be experimentally isolated.

Merkel now proceeds to carry his argument to its logical conclusion (and likewise to a reductio ad absurdum) by denying the gustatory function to all terminal buds, even those within the mouth supplied by the glossopharyngeal nerve, of all vertebrates below the Mammalia.

He finally concludes that both the neuromasts of the lateral line system and the terminal buds are tactile organs, the buds being the more delicate, but, if these are deficient, then the neuromasts may be elevated to a more delicate functional value; both of which conclusions, in the light of our present

knowledge, illustrate the dangers attending an attempt to determine function on the basis solely of observed structure, without adequate physiological control.

The general works contain numerous references to the subject, but usually chance observations or speculative conclusions. Günther says under the caption, *Organ of Taste*: "Some fishes, especially vegetable feeders, or those provided with broad molar-like teeth, masticate their food; and it may be observed in Carps and other Cyprinoid fish, that this process of mastication frequently takes some time. But the majority of fish swallow their food rapidly, and without mastication, and therefore we may conclude that the sense of taste cannot be acute. The tongue is often entirely absent, and even when it exists in the most distinct state, it consists merely of ligamentous or cellular substance, and is never furnished with muscles capable of producing the movements of extension or retraction as in most higher vertebrates. A peculiar organ on the roof of the palate of Cyprinoids, is perhaps an organ adapted for perception of this sense; in these fishes the palate between and below the upper pharyngeal bones is cushioned with a thick, soft contractile substance, richly supplied with nerves from the Nervi vagus and glossopharyngeus."

Regarding the peculiar palatal organ of the cyprinoids, it has been known since Weber's account in 1827 that this is plentifully supplied with taste buds and Weber himself brought forward strong indirect evidence that its function is gustatory. The following observations (and many similar ones might be cited from the literature of sport) are taken from the section on "The Trouts of America" by William C. Harris in the American Sportsman's Library. "The angler cannot resist the belief that the senses of smell and taste are well developed in trout. They eject the artificial fly, if the hook is not fast in the flesh, at the instant they note its non-edible nature, or when they feel the gritty impact of the hook. They will not eat impure food, and they have the faculty of perceiving odors, and various scents attract or repel them. This has been verified from the earliest days of our art, when ancient rodsmen used diverse

and curious pastes and oils, which were seductive to fish; in Walton's day and long after this practice was followed and the records tell us of its success. When I was a boy and the Schuylkill River was swarming with the small white-bellied catfish, than which no more delightful breakfast food ever came out of the water, the only bait used to catch them was made of Limburger cheese, mixed with a patch of cotton-batting to hold it firm on the hook. No other lure had the same attraction for them because, no doubt, of the decided odor of the cheese."

The problems connected with the relative significance of the several sense organs of the fishes have been treated both anatomically and experimentally in the excellent paper of Bateson ('90). After anatomical remarks, based largely on his own careful studies, on the eyes, olfactory organs and gustatory organs, he recounts a series of admirable and well considered experiments made to test the parts played by these organs in the normal feeding of various kinds of fishes.

These observations are grouped under two chief heads, viz., "Senses of Fishes which Seek their Food by Scent," and "The Senses of Fishes which Seek their Food by Sight." Though the taste buds in the mouth and outer skin are described and correctly interpreted in the anatomical part of the paper, these organs are scarcely considered at all in the physiological part, and this is really the greatest weakness of the paper. Since my own observations in part follow so closely in the foot-steps of Bateson (though completed in the main before his paper was accessible to me), and since they are in general confirmatory of his, it will be of interest to review portions of his paper at this time.

He gives the following list of fishes which he has observed "to show consciousness of food which was unseen by them; as, as will hereafter be shown, there is evidence that they habitually seek it without the help of their eyes:"

Protopterus annectens, mud fish.
Scyllium canicula, rough dog fish.
Scyllium catulus, nurse hound.
Raja batis, skate.

Conger vulgaris, conger eel.
Anguilla vulgaris, eel.
Motella tricirrata, three-bearded rockling.
Motella mustela, five-bearded rockling.
Nemacheilus barbatula, loach.
? Lepadogaster gouanii, sucker.
Solea vulgaris, sole.
Solea minuta, little sole.
Acipenser ruthenus, sterlet.

He says, "To this list may almost certainly be added the remainder of the Raiidae, together with the angel fish (*Rhina squatina*) and *Torpedo*." Unfortunately, however, Bateson in his list does not distinguish between those fishes in which smell obviously plays the leading part and those in which taste or touch or both are used to compensate for the reduction of vision, and it is this defect which it is hoped that the present contribution may in part correct.

Most of the forms in the list above are more or less nocturnal animals, but they differ much in this regard. The part attributed to the sense of sight and smell in Bateson's studies is so similar to my own conclusions in many respects that it seems fitting to quote the greater part of his description, especially since the species observed by us are in all cases different. He says, "None of these fishes ever start in quest of food when it is first put into the tank, but wait for an interval, doubtless until the scent has been diffused through the water. Having perceived the scent of food, they swim vaguely about and appear to seek it by examining the whole area pervaded by the scent, having seemingly no sense of the direction whence it proceeds. Though some of these animals have undoubtedly some visual perception of objects moving in the water, yet at no time was there the slightest indication of any recognition of any food substance by sight. The process of search is equally indirect and tentative by day and by night, whether the food is exposed or hidden in an opaque vessel, whether a piece of actual food is in the water or the juice only, squeezed through a cloth, and, lastly, whether (as tested in the case of the conger and the

rockling) the fish be blind or not. . . . . The perceptions, then, by which these animals recognize the presence of food are clearly obtained by means of the olfactory organs, and apparently exclusively through them. I was particularly surprised to find no indication of the possession of such a function by the sense organs of the barbels and lips, or by those of the lateral line. As has been already described, the pelvic fins and barbels of the rocklings (*Motella*) and the lips, &c., of most fishes bear great numbers of sense organs closely comparable in structure with the taste buds of other vertebrates. No one who has seen the mode of feeding of the rockling or pouting (*Gadus luscus*) can doubt that these organs are employed for the discrimination of food substances; but the fact already mentioned, that the rockling in which the olfactory organs had been extirpated did not take any notice of food that was not put close to it, points to the conclusion that they are of service only in actual contact with the food itself." Bateson gives also a considerable list of fishes which he has observed to get their food chiefly by the sense of sight, and he is doubtless correct in asserting that the majority of fishes belong to this class. None of these sight-hunting fishes while living in his tanks appeared able to see their food by night, or even in twilight. None of the fishes which he enumerates as belonging to this class showed symptoms of interest when the juice of food substances was put into the water, and other evidence is brought forward to show that the sense of smell plays little or no part in helping them to discover their food.

I have not studied any of the species mentioned by Bateson, but for the forms studied by me which have an extensive supply of terminal buds on the outer skin I fully confirm most of the statements quoted above save that in determining the part played by sight I did not blind any of my fishes and save that the statement that in fishes of his first group "at no time was there there the slightest indication of any recognition of any food substance by sight" is strictly true of none of my fishes except *Ameiurus*, though in some of the other cases it is approximately true.

The only important respect in which my observations are not in harmony with those of Bateson is in connection with the part played by the sense of taste in some of these types of fishes. I have studied the gustatory reactions of fishes closely allied to the rockling, and having the same arrangement of terminal buds on the barblets and pelvic fins, and am convinced that Bateson's failure to get clear gustatory reactions from these organs was due to the insufficiency of his methods of experiment, rather than to the absence of the function. In general, it may be stated that the part played by the gustatory reflex in the case of fishes having an extensive supply of terminal buds on the outer skin is of vastly greater importance than Bateson appears to have recognized.

The only other paper of importance dealing with the sense of taste in the fishes experimentally which has come to my notice is the great monograph on the senses of taste and smell by Nagel ('94). He investigated the sense of taste in the following fishes:—(1) Fresh water types.

Anguilla anguilla (old and quite young).
Cyprinus carpio.
Barbus fluviatilis.
Leuciscus cephalus.
Gasterosteus aculeatus.
Gobius fluviatilis.
Silurus glanis (young specimen).
Cobitis fossilis.

(2) Marine types.

Pristiurus.
Scyllium catulus and *S. canicula.*
Syngnathus acus.
Uranoscopus scaber.
Lophius piscatorius.

Nagel tested all the fresh water fishes mentioned in this list by bringing bitter, sour, sweet and salty solutions in contact with the skin, without getting any response to the stimulus. Thus, the carp, wels (*Silurus*) and stickleback did not respond

to a stimulation of the skin of the body with quinine, though the last named fish gave an immediate response when the solution touched the lips. He concludes, "In the fresh-water fishes, according to my observations, the power of taste is completely lacking in the outer skin; or, more precisely, in no part except the head is there gustatory sensibility."

For such of these forms as possess no terminal buds on the skin of the body this is doubtless true; but for the other fishes, including doubtless *Silurus* and *Cyprinus*, it is certainly a mistake. In gadoid fishes I got a clear reaction against quinine solution when it was applied to the free fin rays which are known to be supplied with terminal buds, but not from other parts of the skin.

Among the elasmobranch fishes, Nagel found *Scyllium catulus* and *S. canicula* to be sensitive to very dilute solutions of vanilla all over the body and fins. Bitters were not perceived thus, nor oil of rosemary, but they are very sensitive to creosote. He controverts Schwalbe's argument that the terminal buds of the outer skin of fishes probably have a gustatory function by reason of the similarity of their structure with that of taste buds in the mouth, and concludes, "A real sense of taste, such as man and many other animals have in the mouth, appears to be absent in the outer skin of all fishes and Amphibia."

It will appear from the following pages that this conclusion is erroneous. I will merely add here that if Nagel had worked with sapid solutions with which his fishes were presumably already familiar, instead of with substances like sugar and vanilla, toward which no clearly established reflexes had been established in the natural environment of the fishes, his conclusions might have been different.

SECTION 2. TERMINAL BUDS AND THIR INNERVATION.

The terminal buds of the fishes tabulated above, and doubtless many others which might be mentioned, are of the same type and presumably provided with similar innervation by communis nerves, for cutaneous branches of the communis root of the facial nerve are known to reach the areas provided with the

buds in all cases which have been adequately studied. These organs may therefore all be defined morphologically as belonging to the communis system of sense organs, along with the taste buds of the mouth cavity and as distinct from the lateral line organs and all other types of sense organs. In order to support this position there remains merely the proof that the terminal buds and taste buds have a similar function. This evidence is presented in the latter part of this paper.

The terminal buds of fishes have been often described and figured, and I have little to add to the classical descriptions save in the matter of distribution and innervation. Those in the mouth are supplied by branches of the X, IX and VII pairs of cranial nerves, the first two nerves supplying those in the gill regions and the pre-trematic branch of the glossopharyngeus also running forward to supply those on the hyoid arch (tongue). The communis root of the facialis (=portio intermedia of human anatomy) and its geniculate ganglion supply the taste buds on the palate by the r. palatinus facialis (=great superficial petrosal nerve of man), and other buds on the lining of the cheek, on the jaws and on the lips by other branches, some of which are secondarily associated with branches of the trigeminus and most of which have no homologues in mammalian anatomy, though some one or more of them probably represent the chorda tympani.

In *Ameiurus* I have shown ('01) that terminal buds occur in the skin of practically the whole body surface, most abundantly on the barblets and diminishing in frequency toward the tail. These buds (see Fig. 2) rest on a low papilla of the dermis, quite different from that figured by Merkel ('80, Plate V, Fig. 1) for the terminal buds of *Silurus*. His figure shows a much smaller organ, resting upon a greatly elongated papilla in an epidermis which is apparently thicker than in *Ameiurus*. Merkel states ('80, p. 72) that terminal buds always occur on such a dermal papilla. While this is certainly the general rule, we find occasionally instances where the papilla is absent, as on the filiform fins of the hake, where I find the buds embedded

in the epidermis and extending only part way through it, with a layer of unmodified epidermal cells between the bud and the dermis.

All parts of the body of Ameiurus which are supplied with terminal buds are reached by branches of the facial nerve from

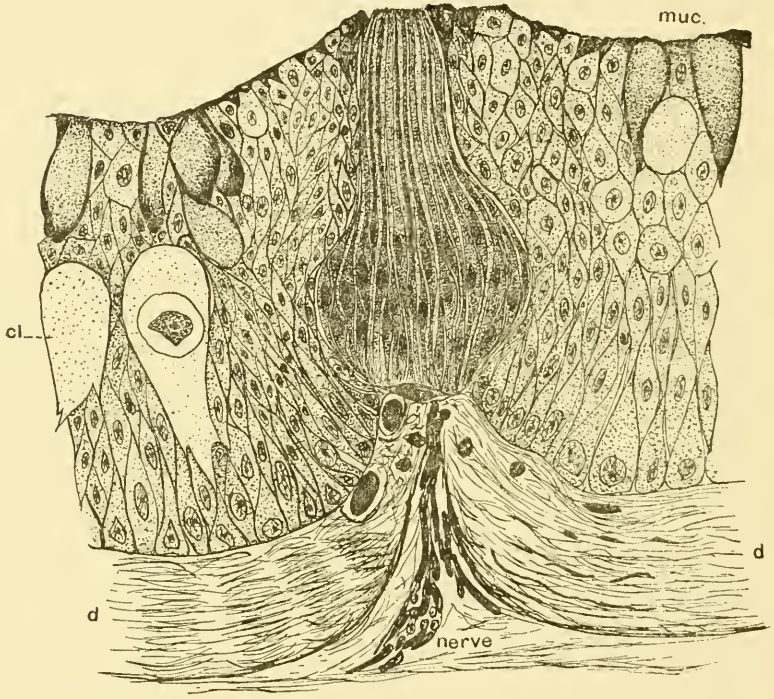

Fig. 2. Section through the skin of the top of the head of *Ameiurus melas*, showing a terminal bud. × 560. (*From the Journal of Comparative Neurology*, Vol. XI, No. 3, Oct., 1901, Plate XVII, Fig. 11. At *d* is the dermis, which is raised into a low papilla under the sense organ and whose center is pierced by the nerve for the organ; *cl*, clavate cells of Leydig; *muc*, mucous cells of the epidermis.

the geniculate ganglion. In other words, the rami from the communis root of the facialis are distributed to nearly the whole outer body surface of this fish. On the distal side of the ganglion these rami usually join themselves to other cutaneous branches which are phylogenetically older, belonging to the general cutaneous and lateral line systems. Even the great re-

current branch into the trunk, the ramus lateralis accessorius, which passes out of the cranium as a practically pure communis nerve, anastomoses with the spinal nerves at their ganglia and its fibers are ultimately distributed along with the general cutaneous fibers from these spinal ganglia. Fig. 3 illustrates the courses of the chief cutaneous branches of the communis system in *Ameiurus melas*, the nerves of all other systems being omitted from the sketch.

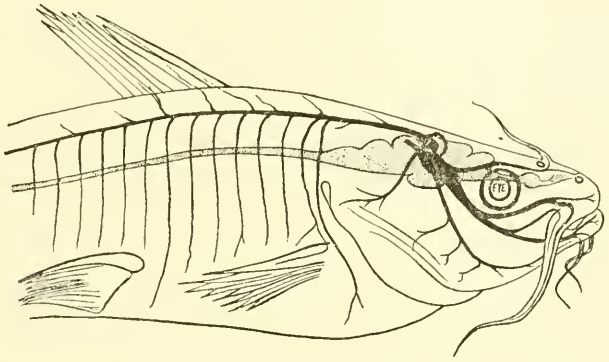

Fig. 3. A projection of the cutaneous branches of the communis root of the facial nerve in *Ameiurus melas*, as seen from the right side. The outline of the brain is indicated by the stippled area and the positions of the eye and anterior and posterior nostrils are indicated. The projection is reconstructed from serial sections, but is not drawn accurately to scale. More detailed reconstructions of the cranial nerves and lateral line sense organs of this fish are given in the *Journal of Comparative Neurology*, Vol. XI, No. 3, Plates XVI, XIV and XV (Herrick, '01).

Proximally of the geniculate ganglion the communis root of the facialis pursues an uncomplicated course to the primary gustatory center within the medulla oblongata. In most fishes this root passes back close to the floor of the fourth ventricle as the fasciculus communis (= fasc. solitarius of mammals) to terminate in the vagal lobe of the same side and receives in its course the communis root of the glossopharyngeus nerve. But in siluroids and cyprinoids, where the very abundant terminal buds of the outer skin are all innervated from the communis root of the facial nerve, the consequent increase in the size of this root has resulted in a great

enlargement of the cephalic end of the gustatory center (vagal lobe) which appears on the dorsal surface of the oblongata as the facial lobe. This structure is paired in siluroids and was formerly called the lobus trigemini, an inadmissible term, since it has nothing whatever to do with the trigeminus nerve. In cyprinoids it is unpaired and is referred to in the older literature as the tuberculum impar.

The cyprinoid fishes also have long been known to have terminal buds (*Becherorgane*) widely distributed over the outer body surface; but neither the innervation of these organs nor the exact composition of the cranial nerves has ever been worked out in any cyprinoid fish. A cursory examination of a series of sections prepared by the Weigert method through the entire head and body of a small gold fish (*Carassius auratus*) has convinced me that the same conditions in general prevail in the cyprinoids as in the siluroids. That is, the enormous size of the vagal lobes of cyprinoids is explained by the fact that these are the terminal centers for the vast numbers of nerve fibers entering the brain by way of the IX and X nerves from the palatal organ, this remarkable structure being crowded over its entire extent with taste buds and probably serving to filter food particles out of the mud taken into the mouth.

On the other hand, the tuberculum impar, or facial lobe, receives the entire communis root of the facial nerve. This root receives fibers from practically all parts of the outer surface of the body, and we may infer by analogy with other fishes that these fibers connect with the terminal buds in these cutaneous areas, though we have as yet no actual demonstration of this fact. The terminal buds of the skin of the head are supplied mainly, as in *Ameiurus*, by way of the infra-orbital trunk. The terminal buds in the skin of the body of the gold fish are not, however, supplied by a ramus lateralis accessorius, or recurrent facial nerve, as in *Ameiurus* and the gadoid fishes, for this nerve, as has long been known, is absent in the cyprinoids.

There is, however, in these fishes an intra-cranial anastomosis between the V+VII ganglionic complex and the IX+X complex, the composition of which has thus far remained un-

known. This proves to be the recurrent branch of the facialis, carrying communis fibers from the geniculate ganglion into the trunk. The details of the peripheral distribution of these fibers have not been fully worked out, but the main path in the gold fish is as follows:

The geniculate ganglion of the facialis is clearly separable from all other ganglionic masses of the trigemino-facial complex and is composed of two portions each of large size. The more dorsal portion corresponds to the greater part of the ganglion in other teleosts and distributes its fibers chiefly by way of the infra-orbital trunk. The more ventral portion sends cephalad a very large palatine nerve and caudad a still larger nerve which represents morphologically, though not topographically, the r. recurrens facialis of the siluroids, etc., or the facial root of the r. lateralis accessorius as found in the cod.

This nerve passes back along the lateral side of the great auditory root, and at the level of the superficial origin of the IX nerve it divides into several strands, one of which passes dorsally of the IX root, the others ventrally. These latter, however, pass upward so as to lie, farther back, dorsally of all of the vagus roots except that of the lateralis branch of the vagus. All of these communis fibers now join themselves to the r. lateralis vagi and, passing through the ganglion of the latter nerve, both components enter the body of the fish bound up in a single nerve trunk in which the fine communis fibers are for a time completely surrounded by the coarse lateralis fibers. The communis fibers go off in successive branches along with lateralis fibers. The details of the distribution have not been worked out, though I think it would not be difficult to do so with the material at hand. It is highly probable that the communis fibers are for the terminal buds sparsely distributed over the skin of the body and that the terminal buds of the trunk are all innervated from these communis fibers in the r. lateralis vagi, just as the buds in the skin of the head are innervated by other communis fibers from the geniculate ganglion of the facialis, an arrangement substantially identical in morphological plan with that of the siluroid fishes.

The conditions here, so far as studied, confirm essentially the conjectures to which I was led from a study of the literature (Herrick, '99, p. 400), and accord so completely with the morphological interpretation there proposed that we merely refer the reader to that passage in the Menidia paper.

SECTION 3. FUNCTIONS OF TERMINAL BUDS.

(1) Experiments on Siluroid Fishes.

The cat fish (*Amciurus nebulosus*) upon which this series of experiments was conducted (except a few experiments specifically designated) were hatched in the open at Granville in the spring of 1901. In October of that same year they were taken to the laboratory and kept through the following winter in tanks. Microscopic examination of the skin and barblets shows that their skin and cutaneous sense organs at this age are practically in the adult condition. During the winter they were fed on various kinds of meat chopped fine, sometimes cooked, but usually raw.

In one small aquarium were kept half a dozen cat fish, several ordinary "shiners" (*Notropis* sp.[1]) and some small "spotted suckers" (*Minytrema melanops* Raf.). Casual observations made during the winter while feeding showed that the shiners use the eyes chiefly in capturing their food. A bit of meat dropped into the water will usually be seized instantly and devoured before it has time sink to the bottom of the tank. After it has fallen to the bottom it is apt to be long overlooked unless the fish happens upon it in its aimless wanderings or unless its attention is called to it by the movements of the other fishes which may be eating it. These fishes, when observed, are usually swimming about in the mid-depths of the tank, not resting near the bottom. I have observed the same behavior in *Menidia*, and other large eyed species.

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[1]Notropis has very small tuberculum impar and vagal lobes, the latter scarcely larger than in the cod, Menidia and physoclistous fishes generally. From this one may safely infer that cutaneous terminal buds are not as highly developed in this form as in the larger cyprinoids.

The behavior of the suckers was totally different. These fishes lie on the bottom most of the time unless disturbed, though if frightened they are very active, swimming powerfully and leaping out of the water. When food is thrown in they never pay the slightest attention, nor are they attracted by the sight of other fishes struggling for the meat. They are exceedingly shy and rarely eat when under observation. They lie quietly much of the time or swim slowly about dragging the fleshy lips of the highly protrusible mouth over the bottom of the tank. If they thus happen upon a bit of meat, this is sucked into the mouth, worked over with the pharyngeal teeth apparently, and then often ejected forcibly from the mouth, to be again taken perhaps and the process repeated—a behavior very characteristic of the way they take the bait, I am told by fishermen.

The cat fish, like the suckers, keep strictly to the bottom of the tank. They are often quiet in the darkest corners or lying under debris, but much of the time are slowly dragging the mental and post-mental barblets along the bottom. The nasal barblets are held projecting well upward, and the maxillary barblets are directed outward and backward, their tips trailing the bottom or waving gently back and forth. They appear never to use their eyes directly for catching food to the slightest degree under the conditions of these experiments. No attention is paid to particles of food thrown into the water, even though they settle down within a few millimeters of the nose or barblet of the fish. The only case observed by me in which the eyes seem to serve in finding food is when a large piece of meat is thrown in and one fish begins to "worry" it. His movements may attract others until as many fish as can reach it are all tugging at it at once. If, however, a shadow is caused to fall upon the water, as by hovering the hand over the aquarium, the fishes are greatly disturbed and dart wildly about. They always seek the darkest corners of the tank and lie under dead leaves resting on the bottom of the tank for the most part, showing that the eyes are not by any means functionless and the fishes are strongly negatively phototactic.

If the cat fishes in the course of their aimless movements along the floor of the aquarium touch a bit of meat with the lips or barblets, it is instantly seized and swallowed. Food in the immediate neighborhood of the fish is not discovered at once, but after a time appears to affect the fish in some way, probably through the sense of smell, as the maxillary barblets begin to wave above more actively and finally the fish becomes restless. He does not find the food, however, unless in the course of his movements it actually touches some part of the body.

During the months of May and June, 1902, more systematic experiments were undertaken with these fish, and since these experiments are typical for those subsequently performed on other species of fishes I shall recount them in some detail. At first a few specimens were taken out in a shallow tray and the attempt made to feed them in various ways under close observation. They were, however, so much frightened by the exposure to bright day light and by the proximity of the observer, in spite of all precautions, that no reactions could be obtained which were at all satisfactory. A bit of fresh meat on a long handled needle could be thrust slowly toward the fish as he lay quietly on the bottom, rubbed over his body, or on the barblets, and even over the lips, without evoking a movement of any kind in response. The same observations was made with the spotted suckers. The fishes in both cases had been without food for several days and were very hungry, but were obviously too much frightened to respond to the food stimulus.

On another occasion the same conditions were prepared, except that a few dead leaves were littered over the bottom of the tray. The fish when placed in the tray immediately sought the shelter of the leaves, and, after a suitable interval to enable them to become accustomed to the place, the feeding experiments were repeated Selecting a fish which was entirely concealed under a large leaf save for a projecting barblet, a bit of meat on a slender wire was gently passed down into the water in such a way as to touch the projecting barblet. It was in-

stantly seized and swallowed. This was repeated many times with several of the fishes.

In subsequent experiments the fish were not removed from their own tank, but the water was drawn off so that it was only about six inches deep. Here they would lie under the leaves and the experiment could be continued with a minimum of disturbance to the fishes. The experiment of touching the barblet with meat was repeated hundreds of times with an almost invariable result that the fish instantly turned and snapped up the morsel. If the meat was merely held very close to the barblet it usually produced no response. The reaction was obtained equally well, no matter which barblet was touched.

In a later series of experiments I found that the fish would almost always turn and seize the meat if it were touched at any point on the head or body. If the tail of the fish projected out from under a leaf and the skin near the root of the tail fin were touched with meat, the fish would turn and seize the meat. This reaction was not so uniformly made at first as that from the barblets, but after a dozen or so of trials it followed with equal promptness and uniformity, the fish apparently requiring a little practice to learn the movement perfectly.

The experiments last described were repeated the next day and by this time it was found that the fish had become so tame that they would take the meat if offered to them in the open without the shelter of the dead leaves, though not so certainly as when under the cover of the leaves, often taking fright from the shadow of the observer's hand or from some other cause.

In none of these cases did the fishes appear to see the bait, or to perceive it in any way other than by actual contact with the skin at some point. If the bait were held a moment in front of them and then moved slowly away they would not follow it. If, however, it touched a barblet and then moved rapidly away before the fish had time to seize it, then the fish would sometimes follow it a short distance.

At this point the relations of vision and smell to these reactions should receive some further consideration. These

young fishes, like their adults, spend much of their time buried under the debris of the bottom, with perhaps a barblet or a portion of the tail only projecting. Under these circumstances it is easy to apply the stimulus to various parts of the skin with the assurance that the contact is wholly invisible to the fish. Many such experiments show decisively that the reaction takes place in the same way whether the fish is able to see the stimulus applied or not. The visual factor being so conclusively ruled out, I have not thought it necessary to blind the fish for further control.

This conclusion of course must be limited strictly to fish of the species and age under investigation. It by no means follows that they may not subsequently learn to use their eyes in finding food, as well as in escaping from their enemies. Indeed, during the later experiments of this series, after the fishes had been fed for several weeks almost daily with meat on the end of a wire, I saw some slight evidence that they took note of the bait by the means of sight, but the observations were in no case conclusive. Whether the adult *Ameiurus nebulosus* ever uses the eyes in the capture of food, I have no definite information, though from the habit of spending much of the time during the day completely buried in the mud and of feeding chiefly at night, it is very improbable that they do so. With the channel cat fish, *Ictalurus*, the case is certainly different.

Mr. I. A. Field tells me that while fishing for bass in the Black River, Ohio, he has sometimes caught large specimens of *Ictalurus* with live minnows as bait. The current was swift and the minnows were kept off the bottom of the river and in motion all the time. At the meeting of the American Association for the Advancement of Science at Pittsburg, July 1, 1902, in the course of a brief report upon these experiments, I asked the question whether any one ever caught a cat fish on a spoon hook. Dr. L. L. Dyche stated that he has occasionally caught the channel cat (*Ictalurus*) on a spoon in a small lake, but only in bright sun light. Dr. Eigenmann stated that *Ictalurus* has much better eyes than *Ameiurus*. They are not only larger,

but the retinal pattern is more nearly like that of other fishes, while that of *Ameiurus* is decidedly degenerate.

The part played by the sense of smell is much more difficult to determine. As intimated above, I have evidence that the gustatory organs of the skin can function only in contact with the sapid substance. The most highly flavored food can be held within a millimeter or two of the barblet or lips without calling forth the characteristic instantaneous reflex. I will narrate one experience which was many times repeated in a variety of modifications. Three fishes were lying quietly under a small water-soaked leaf. A bit of rather stale beefsteak with a strong odor was held on the tip of fine wire over the edge of the leaf under which they were lying and separated by a centimeter or two from the nostrils of the fishes. The leaf was considerably corroded by decay and doubtless the odor could freely permeate it, though it was nearly or quite opaque. After some ten seconds the fishes began to move restlessly about in circles under the leaf, which was soon swept away by their movements. As a rule the fishes swam in narrow circles close to the bottom and for a long time failed to find the meat, though they seemed to be aware of its general position for they never circled far away. If the meat were very slowly moved across the aquarium, the fish could be drawn in this way after it for a considerable distance, though the meat was never found unless in the course of their apparently aimless movements one of the fishes came in contact with it, when it was instantly snapped up.

This aimless circling movement may be termed provisionally the *seeking reaction*, since it is so different from the characteristic movement made when the stimulus is in contact with the body—a sharp turn of the body and instantaneous seizing of the bait—which I shall term the *gustatory reaction*. Unfortunately, I have not had opportunity as yet to carry out extirpation experiments on *Ameiurus* to determine decisively the part played by the olfactory organ in this reaction (compare the experiments on the tom cod narrated below).

The fishes upon which these experiments were performed have unfortunately been lost. At the present time I have a

fresh lot of Ameiurus fry under observation and have already verified many of the conclusions reached with the first lot. But this second collection of fishes has not at the time when this report is submitted been in captivity long enough to become sufficiently accustomed to their new surroundings to feed freely and fearlessly. After some months of further preliminary observation I hope to carry on experiments which may shed some light on the sense of smell in these fishes. But this must be reserved for a later report.

We must content ourselves at the present time, then, with the inference that the sense of smell plays at least a small part in these reactions, for the animals became slightly restless in the proximity of the stimulus, though they were not in contact with it; this, however, appears never to provoke a definite reaction of seizing the food, but merely a vague reaction in search of food. On the other hand, physical contact with the irritating substance causes a definite and precise reaction which is practically constant. This points either to touch or to taste.

To test the relative part played by stimulation of these two sets of sense organs the following series of experiments was performed. A half a dozen fish in an aquarium were tested a score of times with fresh meat on the tip of a wire, as in previous cases. The reaction was obtained uniformly, no matter what part of the body or head was touched. Half an hour after the close of these experiments a bit of cotton wool was wound around the tip of a wire and the fishes were tested with this exactly as they had been with the meat. For the first six trials the barblets only were touched. The fish in each case turned and seized the cotton as promptly as the meat had been taken. The cotton would be immediately dropped. After a few more trials the fishes would generally turn when touched, but would check their movement before the cotton was actually taken into the mouth. Several specimens were now tested on the trunk with the cotton. One or two turned completely around and took the cotton, but generally there was a slight movement only toward the cotton, which was checked before the cotton was reached. After a few further tests, the fishes

would usually pay no attention to a contact with the cotton on the skin of the body and the reaction by the barblets became uncertain, until finally the cotton could be freely rubbed over the barblets or lips of some of the individuals without producing any response.

These experiments were many times repeated, sometimes using white cotton, sometimes red cotton and sometimes fresh meat. The reaction was uniformly obtained with the meat. If at the close of a few experiments with the meat a minute pledget of cotton was substituted for the meat, there was feeble or no response from rubbing the body with the cotton, though upon touching the barblets the fish would usually turn and often would seize the cotton and drop it again at once. After several repetitions, the fish became wholly indifferent to the cotton no matter how it was applied, or they would if touched upon a barblet turn toward it without biting it. They were now again tested with bits of meat. This they took as eagerly and as precisely as before, showing that they were still hungry.

After the interval of a day or two the fishes would still appear to remember the cotton and I rarely after the first trials got a prompt "gustatory" reflex with the cotton. If they noticed it at all, they would turn slowly and touch it with the lips or a barblet in a tentative or inquiring manner, only to turn away again without taking it into the mouth. This deliberate movement may be designated for reasons to appear immediately as the *tactile reflex*, as distinguished from the instant seizing of food, the "gustatory reflex."

These experiments seem to show that in the reactions to the meat both from the barblet and from the skin of the body the sense of taste and touch both participate. This is in accord with the known innervation of the skin and barblets, for all parts of the body surface receive general cutaneous (tactile) nerves and all parts are plentifully provided with terminal buds (taste buds) which are innervated by communis (gustatory) nerves. The experiments further suggest that these two sensory factors can be experimentally isolated by training.

The fishes having become accustomed by brief training to

make the simple reflex of seizing the food under the stimulus applied to any part of the barblets or skin, and doubtless utilizing both gustatory and tactile sensations, the gustatory factor is eliminated by the substitution of cotton wool for the meat. The tactile sensation alone proves to be sufficient to set off the reflex after the training previously given. The stimulus is, however, never followed by satisfaction and is soon given up, the fishes after further practice not reacting to the tactile stimulus alone. If, however, the gustatory sensation is added, by the substitution of meat for the cotton, the original reflex is given as promptly as before. This would seem to indicate that, while the tactile sensation alone is not sufficient to maintain the reflex, the addition of the gustatory element is sufficient, and therefore that the gustatory element is the essential element in setting off the reflex. This hypothesis was tested by an extensive series of experiments similar in plan to those last described.

In general there was no noticeable difference between the reaction to the white cotton and that to the red, though in some cases, especially toward the end of the series of experiments, after the fishes had learned to pay no attention to white cotton when touched at any point by it, they would sometimes turn and touch the red cotton with the lips or a barblet, immediately to turn away again without biting the cotton as they did at first. The reaction is not the quick turn and instant seizing of the bait which I have termed the "gustatory reaction," but a more deliberate movement similar to what I termed above the "tactile reaction." This occurred only when the cotton was in plain view at the time of the contact and is probably in this case partly a visual response called forth by the similar appearance of the red cotton and bits of beefsteak on which they were habitually fed. It was not by any means constant, for, in general, after the first few days contact with neither color of cotton called forth any response whatever.

After this result was reached, I dipped the pledgets of white cotton in the filtered juice of fresh beef and touched the body surfaces and barblets with them in the same way as be-

fore. In all cases I got a typical "gustatory" reaction exactly the same as with the meat, and this reaction persisted after many trials with no diminution. The cotton was taken instantly into the mouth and tugged vigorously. No amount of training served to eradicate or to weaken this reflex.

I next prepared a small bulb syringe, with the delivery tube drawn out to a very fine point. This was filled with the water in which the fishes were and a fine jet directed against their bodies. They either paid no attention or were disturbed and swam away. I now substituted for the water in the syringe the juice of raw beef pressed out and strained. When a jet of this fluid was directed against the side of the body, the fish always instantly turned and tried to take the end of the syringe. The reaction was identical with that produced when a corresponding part of the body is touched with raw meat. I invariably got the reaction both from the sides of the body as far back as the root of the tail fin and from the skin of the head and barblets.

I also tested the fishes with bits of red brick held in forceps. The forceps seemed to frighten the fishes. They either paid no attention to the contact with the brick (when touched in such a way that they could not see the point of contact), or else the harsh contact seemed to frighten them. I then touched them on various parts of the body and the barblets with bits of brick which had been soaked in raw meat juice. In most cases they would turn and touch the brick with the lips or take it into the mouth, but often they seemed frightened and would swim away. I then gave them a few bits of meat with the forceps and found that they took it eagerly, being very hungry, but it had to be given more cautiously than with the wire, as they were afraid of the forceps if they saw them clearly.

Next I dropped bits of brick which had been soaked in meat juice in front of the fishes as they lay under leaves with the barblets projecting beyond the edges of the leaves. In all such cases upon touching the brick with a barblet they seized the brick and bit at it viciously. Often they would return to it a second or third time and try to bite it. I dropped similar bits

of brick which had not been soaked in meat juice in front of them in the same way, but they paid no attention to them, or in a few cases they would touch them with the barblets and then swim away again ("tactile" reaction). They never attempted to bite them. Clearly they taste the meat juice in the bricks when they are touched by a barblet, and the experiment when the body was touched by a similar brick held in forceps shows that they taste the juice by the body also.

On one occasion I tested the fishes with pieces of cooked meat that had been long boiled so that nearly all the extractives were drawn out. The experiments were conducted just like those with the raw meat, but the fishes gave by no means so clear reactions to it. Upon touching the sides of the body, the fishes usually paid no attention to the stimulus, treating it just as they did cotton. I then touched the barblets a few times and to this they would generally react by turning and taking the meat, but not always nor so promptly as with fresh meat. Upon testing the sides of the body again after this experi- experience, I got a reaction. The fishes would turn and touch the meat with the barblet or lips before taking it, rarely giving the quick reaction characteristic of fresh meat. Evidently the cooked meat has less taste to the fishes than fresh meat and this interferes with the reaction. They eat the cooked meat when they are sure that it is edible.

These experiments, which were all many times repeated and controlled, I think show conclusively that practically the whole cutaneous surface of *Ameiurus* is sensitive to both tactile and gustatory stimuli and that the latter call forth characteristic reflexes which are of the greatest value to the fish in procuring food. The fish normally reacts to contacts on the body by both types of stimuli—to the mere tactile stimulus (if at all) by a tentative movement calculated to bring the doubtful substance into contact with the more highly sensitive barblets or lips, but to the tactile stimulus accompanied by the gustatory by an immediate, rapid and precise movement calculated to seize the food. This latter reflex is unvarying and is very persistent under a great variety of forms of stimulation. The former

("tactile") reflex is less stable, and may be readily eliminated by a simple course of training. Clearly the gustatory element of the sensation complex resulting from a contact with a sapid substance is more important than the tactile element.

It is clear that in order to call forth the characteristic "gustatory" reflex the stimulus must be quite strong and rather sharply localized. For when there is only a small amount of meat juice diffused through the water, as by the presence of a piece of fresh meat near the fish, he is not able to localize it accurately, but exhibits only the "seeking reaction." I have not as yet been able to convince myself whether the fish could accurately locate a strong and sharply localized gustatory stimulus with no tactile element. In all the experiments in which meat juice was directed against the body with a pipette or syringe there was doubtless some tactile effect produced by the impact of the jet. We know from the experiments that pure tactile stimuli can be accurately localized on the skin, and there can be no doubt that under normal conditions these assist in the localization of the food object.

(2) Experiments on Gadoid Fishes.

The preceding experiments were all carried on in the zoological laboratory of Denison University; the experiments on marine fishes which follow were made during the summer of 1902 at the U. S. Fish Commission laboratory at Woods Hole. The feeding reactions of three types of gadoids were studied; viz., young pollock (*Pollachius virens*) about 10 cm. long, hake (*Urophycis tenuis*) about 20 cm. long, and young adult tom cod (*Microgadus tomcod*).

As is well known, the hake and tom cod have a mental barblet which is known to be abundantly set with terminal buds and which receives both communis and general cutaneous innervation. In all three types the lips are freely supplied with terminal buds and there is a recurrent branch of the facial nerve, the ramus lateralis accessorius, which carries communis fibers into the trunk to supply the terminal buds found on the fins, especially the free rays of the ventral, or pelvic fins. These

fins are far forward under the throat. In the pollock they are but little modified, in the tom cod two rays are about twice as long as the others and for about half their length they project freely below the rest of the fin. In the hake all of the rays of this fin are suppressed save these modified free rays, so that the fin is filiform, branched at the end. Microscopic examination shows that the terminal buds are more abundant on the more highly modified fins. The hake also has a free filament on the dorsal fin produced by the extension of the third and fourth rays beyond the others. I have not examined this free filament microscopically, but know that it receives communis fibers from the r. lateralis accessorius and have no doubt that it also has numerous terminal buds, as the experiments show it to be very sensitive to gustatory stimuli. The pollock have very large eyes and are excellent visualizers. When food is thrown into the water they dart for it and in general they take their food by the visual reflex. So keen is the vision that it would be difficult to carry on any experiments such as I have done with the other two species without first blinding the fish. Nor do they habitually drag the bottom with the free ventral fin rays as the others do. I have therefore not devoted much attention to this species, preferring to study more carefully those species in which the gustatory reflex plays the greater part in the life of the fish.

The hake (*Urophycis tenuis*). These fishes, like the tom cods, readily adapt themselves to life in captivity and are easily experimented upon in small tanks. They are excellent visualizers, though not so much so as the pollock. When bits of meat are thrown into the water they usually catch them before they fall to the bottom and their keen vision makes difficult such experiments as I carried on with the cat fishes. They do not seem to recognize by sight food lying on the bottom, but only when it is in motion. But bits of meat, fish or clam lying on the bottom are usually found by the aid of the free ventral fins. These fishes spend much of their time in slowly swimming in an apparently aimless manner close to the bottom of their tank. During these movements the filamen-

tous pelvic fins are so held that their tips drag the bottom. These fin rays are quite long and they are usually directed obliquely forward, outward and downward with the two branches of each fin widely divaricated, so that the four tips touch the ground in a line transverse to the body axis at about the level of the mental barblet. In this way the bottom under the fish and for a short distance on either side is thoroughly explored as the fish swims over it, and all food particles with which the barblet or free fin rays come in contact are taken by a quick and precise movement similar to that set off in the siluroids by contact with their barblets. Bits of meat or clam on the end of a slender wire could be laid on the bottom of the tank and then slowly moved up under or behind the fish and the reflex from the ventral fins tested in this way. Such experiments, however, had to be made with great caution and many times repeated to rule out possible visual sensations which likewise call forth an immediate reflex.

Bateson ('90, a) records similar reactions with the rockling (*Motella*), a gadoid fish with the same general structure and distribution of terminal buds as the hake, but with better developed barblets. (On the structure of the pelvic fins of *Motella* compare Bateson's account on p. 214 with that on p. 234 of the same volume). Bateson, moreover, got the same reflex with fishes which had been blinded, and I have not thought it necessary to repeat this experiment, for my fishes give sufficiently clear evidence that this reflex from the fins is wholly independent of vision. We have, however, to investigate the parts played by tactile, gustatory and olfactory sensations.

Bateson's remarks ('90, a, p. 214) in this connection on the rockling may be quoted here. The three-bearded and the five-bearded rocklings are nocturnal and lie still all day. "Generally, both the animals take no notice of food until it has lain in the water some minutes, when they start off in search of it. The rockling searches by setting its filamentous pelvic fins at right angles to the body, and then swimming about feeling with them. If the fins touch a piece of fish or other soft body, the rockling turns its head round and snaps it

up with great quickness. It will even turn round and examine uneatable substances, as glass, &c., which come in contact with its fins, and which presumably seem to it to require an explanation. The rocklings have great powers of scent and will set off in search of meat hidden in a bottle sunk in the water. Moreover, a blind rockling will hunt for its food and find it as easily as an uninjured one."

The above, taken in connection with other passages, shows that this author considers that the food is found largely by scent and that the fin reaction is essentially tactile, though he has seen the sense organs on the pelvic fins and recognizes their resemblance to taste buds.

Examination of stomach contents shows that the normal food of these hake is largely crustaceans, particularly shrimps. I fitted up a tank with some sea weed and put into it a large number of prawns (*Palaemonetes*), mostly living, but some dead. Upon putting the hake into this tank, they immediately ate some of the dead prawns from the bottom and afterwards caught the live ones, but very slowly and with many failures. The response seems to be wholly visual. These fishes would repeatedly pass directly over living prawns, touching them with the fins or being brushed by their antennae, but so long as the crustaceans were quiet they seemed not to notice them. If, however, a prawn was killed and crushed and thrown back into the water, it was immediately found. Upon another occasion I put a live clam into the tank with the hake, where it remained for several days, with siphons greatly extended. The fishes repeatedly brushed over this siphon with their free fins but never paid any attention to it, though if a similar siphon were cut off from a live clam so as to allow some of the juices to escape, it would be immediately taken and eaten. Evidently live food is not clearly located by the gustatory organs of the fins.

Besides observing as fully as possible the normal feeding habits of the hake, I experimented upon the reactions to stimuli applied to both the pelvic and the filamentous dorsal fins. As mentioned by Bateson, the pelvic fins are freely used

to explore all manner of substances which may attract the notice of the fish, whether edible or not. After these fishes had become accustomed to being fed small bits of meat or clam or mussel (*Medeola*) in their tank, they immediately swim toward any small unfamiliar body with the pelvic fins thrust forward to touch it before the mouth reaches it. Sometimes the tips of these fins close over it with a movement strongly suggestive of grasping, though of course this they cannot do.

Upon testing by contact with meat or other bait, the free dorsal filament is found to be quite as sensitive to gustatory stimuli as the filamentous ventrals. The reflex in this case is very characteristic and constant—the fish upon touching a savory morsel checks its forward movement and immediately "backs water" so as to reverse the movement of the body until the object is directly above the mouth, when it is taken at once. This reflex usually (though not so invariably) follows a contact of meat upon any part of the dorsal fin, as well as the free filament. The reflex rarely fails when any one of the filamentous fins is touched by freshly cut meat. After meat has been in the water for fifteen minutes or more it seems to lose its savor and the fins may be repeatedly dragged over it without calling forth a response, and the same is true of the barblet and lips.

I tested the filamentous fins with a wisp of cotton wool on a fine wire, as I did the cat fishes. It was rarely noticed at all by the pelvic fins, but at the first contact with the filamentous dorsal the fish reacted just as he did to meat with which he had been tested immediately before. Upon repetition the response was soon discontinued. For a few tests the fish would pause, and perhaps back up slowly so as to smell the suspicous object or touch it with the barblet, but it was not taken into the mouth. After from two to ten tests no further attention was paid to the cotton, or the fish would pause a moment without backing up. This experiment was many times repeated in the course of the first day of its trial and daily thereafter for some time. If three or four hours intervened between two series of about twenty tests, the first one or two tests of the second se-

ries might be followed by an incomplete reaction, but after that usually no notice was taken of the cotton. The fishes apparently remembered the preceding tests. But if more than 24 hours intervened between tests, the process of training usually had to be gone over again.

The fact that the hake does not appear to remember the difference between the pure tactile stimulus, and the tactile plus the gustatory for so long a time as the cat fish does is probably to be explained by the fact that the number of taste buds on the filamentous fins of the hake is much less than that on the barblets of the cat fish and therefore the gustatory element in the sensation complex is doubtless much less in the hake. The whole course of experiments indicates that the response is in fact much more strongly tactile in the hake.

During the course of these experiments I often alternated bits of meat with the cotton wool, and at other times substituted cotton that had been soaked in clam juice. In these cases I always got the characteristic gustatory reaction by all of the filamentous fins, no difference being observable between the reaction to meat of clams or fish and that to cotton soaked in filtered clam juice.

I also tested the hake with gelatin which had been soaked up in cold water. Shreds of the well softened gelatin were fastened to the end of a wire and brought into contact with the body surface. The reactions were identical with those obtained with white cotton. The gelatin shreds are very nearly colorless and absolutely tasteless to my tongue. But to the sense of touch they are almost exactly the same as the bits of fresh clam meat with which most of these experiments have been conducted. The hake at first would take the bait when the filamentous dorsal was touched, but if the gelatin was taken into the mouth it would be immediately rejected and after a few trials the fish would no longer respond to the stimulus. He acted in the same way when the pelvic fins were stimulated. Shreds of the softened gelatin falling through the water were sometimes noticed, but rarely taken into the mouth, and if so were immediately rejected. Similar shreds lying on the bottom

were neglected, even though the barblet and filamentous fins dragged over them repeatedly.

I next took small clam shells that had been lying long in the tanks containing the fish and were thoroughly cleaned of fleshy matter and which the fishes had not paid any attention to for days. These I dried and warmed and then filled with melted gelatin which had been previously softened up in cold water. Upon cooling there results a mass, colorless, tasteless, and odorless, which feels almost exactly like the flesh of a clam, which had often been fed to the fishes in this way. Upon dropping these shells into the water, the fishes eagerly snap them up, feel of them with the lips or barblet, and then bite into the gelatin. They immediately reject the gelatin and they never repeat the process. Even if they draw the fins or barblets repeatedly over the shells and the contained gelatin, they never again pay any attention to them.

I also repeated with the hake the experiments which I had previously carried out upon the cat fish, using a fine pointed pipette and sapid solutions. The fishes were in all cases first tested with sea water taken from the tank in which they were swimming. On one occasion (the first test made) a jet of water directed against the filamentous dorsal was followed by the characteristic backward movement of the fish, so that he finally received the jet in the face. He turned and tried to take the point of the pipette in his mouth—a purely tactile reflex apparently. This response I never got again with this or any other fish, though occasionally the fish would stop, hesitate a moment, and then swim on, paying no further attention to the stimulus. If the jet of water is directed against the pelvic fin while it is extended and searching the bottom for food, the fin is usually quickly withdrawn and pressed against the side of the body.

The pipette was then filled with the freshly prepared and strained juice of the mussel (*Medeola*), and this was directed against the fish in the same way. The fishes responded instantly just as when stimulated by meat, whether the jet was directed against the filamentous dorsal, or the dorsal fin at any

part, or the side of the body or the free pelvic fin. The reflex is immediate and unmistakable, more sharply defined than I usually get by contact with the meat of the same mussel. The experiment was many times repeated, always with the result that the jet of water was ignored or avoided, while the jet of mussel or clam or crab juice was eagerly sought, the fish usually snapping at the end of the pipette.

I have carried out no systematic chemical experiments to determine the gustatory preferences of the fishes, having shaped my experiments so far as possible along the lines of the normal feeding habits of the species studied. Nagel and some other previous students of these problems have relied chiefly on reactions to unpleasant stimuli and the reader is referred to their works, though I consider this a less satisfactory line of inquiry than the study of normal reactions to food substances. The few fragmentary observations which I have made with chemical stimulants I shall, however, record in their appropriate places.

Specimens of hake were tested with a 0.2% solution of hydrochloric acid made up in distilled water, the acid being directed against the body by means of a fine pipette. The dorsal and ventral fins, the sides of the body and the lips were tested. When first tested on the fins one hake turned and tried to take the pipette, much as he did with the clam juice. Afterwards this fish, as well as all the others from the first, seemed rather to dislike the acid and would swim slowly away. There is no constant reaction, however, and in fact the fishes act very much as they do when a jet of simple sea water is directed against them. They do not appear to dislike the acid intensely. Later I tested these fishes with a 1% solution of hydrochloric acid in sea water. This is decidedly unpleasant and is uniformly avoided.

The experiments recorded seem to show clearly that the hake receives both tactile and gustatory stimuli by means of the free fin rays and to some extent doubtless by other parts of the outer body surface. What rôle may be played by the sense of smell remains obscure. To test the powers of locating concealed food the following experiments were tried.

In a tank containing two hake which were very hungry I placed a piece of fresh clam meat concealed between two small, old and thoroughly clean clam shells which had been lying for some time in the bottom of the tank. The fishes did not seem to smell the meat at a distance and so be attracted to the spot where the shells were, but if in the course of their aimless movements along the bottom of the tank they passed over the shells they generally stopped a moment, smelled around and then passed on, first feeling over the whole area of the shell with their free fins. As time passed, this reaction became less clear until after some fifteen minutes they generally passed over the shells without paying any attention. They never found the meat. This experiment was many times repeated with the same result. The sense of smell can play no strong part in the locating of their food. It may play some small part, though I incline to believe that the interest which the fishes show in the concealed bait is excited by a vague stimulus to the terminal buds on the fins. Compare the experiments made after the extirpation of the olfactory organs in the tom cod, described below.

The tom cod (*Microgadus tomcod*). These fishes are much less active than the hake, spending most of the time lying quietly on the bottom of their tank. They have not so keen sight as the hake and pollock, but still obtain much of their food by this sense, catching food thrown in before it reaches the bottom. They do not catch live prawns in captivity so well as the hake do, yet prawns and other active crustaceans are found in the stomachs of specimens taken with the seine. The dorsal fin lacks the free filamentous rays and is not especially sensitive to gustatory stimuli. The ventral fins are, however, very efficient in locating sapid substances lying on the bottom; they are shorter than those of the hake and are not thrust forward, but incline slightly backward. Like the hake, the tom cods spend much time in slowly exploring the bottom, though they assume a very different position, with the head directed downward at an angle of some 30° to 45° with the bottom, so that the tips of the barblet and ventral fins just drag

the bottom. When food particles are located, they are snapped up by a quick lateral movement similar to that of the cat fishes. Sometimes, however, stimulus of the ventral fins is followed by a reversed swimming movement, the fish backing up to take the bait. At other times the fish when exploring the bottom swims slowly backwards, so that no change of direction is necessary when food is located.

I made a series of tests with cotton wool and cotton dipped in clam juice similar to those described for the hake and with the same results. I also repeated the tests made with sea water and with strained clam juice by the aid of a pipette, with identically the same results as with the hake. After a few tests the fishes ignore sea water and plain cotton, but invariably respond to cotton soaked in clam juice and to the juice itself as they do to meat. The tom cod reacts to bits of clear gelatin soaked up in water essentially as the hake does.

I also tested the tom cod with hydrochloric acid, 0.2% in distilled water and 1% in sea water. Both are obviously avoided. I filled a fine pipette with a solution of quinine sulphate in sea water, about 0.1%—a very bitter solution. The tom cod swims away immediately if applied either to the lips or to the pelvic fins, but appears not to notice it if applied to other parts of the body.

Within two old clam shells which had been lying in the tank with the tom cods for several days and had remained unnoticed was placed a piece of fresh clam. They were then closed together and laid on the bottom of the aquarium containing a tom cod. Shortly the fish passed near it, appeared to perceive it, turned from his course and passed and repassed the spot until the shell was located, *apparently* by smell, by a method of "trial and error." Then he rooted at the shell vigorously until the two halves were separated and he could get the meat. I repeated this with a piece of squid within the shells with the same result. I tried two empty shells in the same way. He saw me put them into the water, came up to investigate, smelled(?) of the shells, and went away without so much as touching them and never came back to them again.

These experiments were repeated in many forms many times. In most of these cases the efficient organ in discovering the presence of the food was almost certainly the pelvic fin. At least, this alone *located* it. For the fish swam about (possibly feebly smelling something good) but did not make a definite movement toward the bait until the fins were dragged over the crack between the two shells containing it, from which the juices were doubtless being diffused out into the surrounding water. *Then* he backed up in the typical way. If the bait was not found within a very few minutes, it was left unnoticed, even though subsequently uncovered.

These fishes almost invariably find a concealed bait, though the hake rarely does so. The hake seems to perceive the odor or savor of the food, for he lingers about the spot where it is concealed, but never makes a movement to uncover it. The tom cod, on the other hand, actively pushes things about with the snout until the bait is discovered. But, unlike the gadoid fishes which Bateson describes, these fishes do not get the scent of the food at any considerable distance and then search for it. They do not notice the bait until within a few centimeters of it, and there is no evidence that the sense of smell assists at all in the localization.

To test this point the olfactory organ was extirpated in several tom cods which had given the reaction last described clearly. Several ways of performing this operation were tried. The most successful method was to etherize the fish sufficiently to keep him quiet, and then operate in a shallow tray with the mouth kept under water, cutting off the olfactory nerves or crura with a sharp scalpel. The wounds suppurated badly, but appeared to give the fish no serious trouble, as they fed normally from the second day onward. Without going into the details of the observations, I may say that after the third or fourth day the fishes took their food in all respects like uninjured fishes, so far as could be observed. They gave all the characteristic reflexes that have been mentioned above, including the discrimination between cotton wool and cotton dipped in clam juice and between sea water and clam juice ap-

plied with a pipette, etc. The operated fish would locate a concealed bait by means of the pelvic fins exactly as the normal fish does and he would similarly root it out and eat it. In short, the gustatory reflexes, so far as I have observed them, were absolutely unmodified by the operation. That the olfactory apparatus was totally destroyed was verified by autopsy dissections made after the close of the observations.

(3) Other Fishes.

The sea robin (*Prionotus carolinus*). The three finger-like rays of the pectoral fins of the gurnards have long attracted the attention of zoologists, and the American species of *Prionotus* have been made the subject of a careful research by Morrill ('95). He finds that, as in the European *Trigla*, the free rays are totally devoid of terminal buds or other specialized sense organs and that the sensory nerves with which these free rays are so abundantly supplied end free, like tactile nerves in general.

He also made some interesting physiological experiments. The normal food of these species so far as known is small fish, young clams, shrimps, amphipods and other small crustacea, squid, lamellibranch mollusks, annelids and seaweeds (Linton, 1901, p. 470). They are constantly feeling about the sand, turning over stones and feeling under them, etc., with these free rays and undoubtedly find their food largely in this way, especially the annelids, mollusks and crustacea. But in captivity the eyes are used chiefly in securing the food. Morrill writes further, "In order to test the use of the free rays independently of sight the crystaline lense and cornea were removed from some fish and in other cases the cornea was covered with varnish, balsam or tar. The repeated experiments were negative in their result, as the fish paid no attention to the food, even when it was placed in contact with the free rays." Morrill concludes "that the free rays have been modified for tactile purposes, and that they are mainly if not altogether used in searching for food."

Morrill's dissections leave it uncertain whether the free rays

of the pectoral fins receive communis nerves, as they should do, of course, if these organs had given evidence of gustatory powers. The only source of communis fibers for this fin would be through the ramus lateralis accessorius (r. recurens facialis). Stannius ('49, p. 49) did not find this nerve in *Trigla gurnardus* and *T. hirundo*. I dissected a specimen of *Prionotus carolinus* and found the same to be true here, so that it can be taken as assured that no communis nerves reach the pectoral fin in this species.

After an examination of the feeding habits of the adult sea robin and of young specimens about 10 cm. long, I quite agree with Morrill, that the reaction to food particles by the free fin rays is tactile only, with no gustatory element. When adults are fed with fresh clams or mussels, the shells split open to expose the meat, they turn and bite out the meat as soon as a free ray touches the soft flesh. Young fishes did not give this reaction so invariably, and evidently relied much more on sight. Clean clam shells filled with melted gelatin were reacted to like the fresh clams once or twice by each fish, but usually were thereafter ignored.

The free rays constantly stir up the sand and gravel of the bottom. If soft edible particles are touched, the head may be turned to snap them up, especially with old fishes; with younger ones this usually does not happen unless the particle is seen while in motion. In fact, with these younger fishes the purpose of the activity of the free ray sseems to be in the main the agitation of particles on the bottom to bring them into the range of vision. Almost any unfamiliar object, such as a bit of coal or a brightly colored pebble or any soft article, if seen while in motion, will be apt to be taken into the mouth. The analysis is done here, not by the peripheral cutaneous organs. All small objects thrown into the water are taken into the mouth as they fall; bits of filter paper, gelatin, etc., will be taken and immediately rejected. The same bit of paper or excrement may be taken and rejected a half dozen times in rapid succession, the reflex following in a perfectly automatic way as soon as the moving object is seen. Small worms when thrown into the water would be captured before they had time to reach the

bottom. But if placed on the bottom they would seek shelter under pebbles and remain unnoticed until they were stirred up and sent floating off, when they would be seen and taken at once. The free fin ray was observed to touch the worm when concealed without evoking a response. A moment later the worm was set in motion and taken at once.

I got no evidence that the fishes smell or otherwise detect the presence of food at a distance or concealed from sight and touch. Meat enclosed between clam shells, which a tom cod would have secured within a minute or two, remained unnoticed, though the outsides of the shells were repeatedly fingered over by the free rays and similar bits of meat were taken at once if in motion near the fish.

The young sea robins eat crab meat well. I made a strong extract of crab meat and filtered it. Now with a fine pipette a jet of clean sea water was directed against the free pectoral fin rays. There was no response, or if the jet was strong the fin was folded against the body. The extract of crab applied in the same way with the pipette gave the same result. Even when the jet is directed against the lips, the fish usually pays no attention or is disturbed and swims away. This would seem to indicate that the sense of taste is absent or very feeble on all of the exposed parts of the body. Thus the absence of special gustatory sense organs, of communis nerves and of gustatory reactions from the free rays of the pectoral fins serve as mutual controls.

The king fish (*Menticirrhus saxatilis*). The fishes have a short, thick mental barblet and they were studied to compare their reactions with those of the siluroid and gadoid fishes. Most of the types of experiment made previously on the latter fishes were repeated on the king fish Without going into details, the experiments seemed to show in general that the king fish is not a pure visualizer, though vision is somewhat used in finding food. This seems to be in the main a tactile reaction, as most of the food taken was by contact and non-nutritrous substances were generally taken if they felt like food. For instance, colorless gelatin is taken at the first contact and repeat-

edly thereafter for an indefinite number of times, though in each case it is at once rejected as soon as it enters the mouth. The sense of taste seems to be limited to the mouth and I found no evidence of a gustatory reaction by the barblet, though the experiments were not sufficiently numerous or varied to be conclusive. They do not find a concealed bait.

The toad fish (*Opsanus tau*). These fishes were experimented upon at the same time as the hake and tom cod and by the same methods. The toad fish never found a concealed bait and never seemed to get food by any other reflex path than the visual or tactile. The fleshy cutaneous appendages of the skin were especially tested to bring out possible gustatory reactions, but with negative results save for those bordering on the lips, where it was impossible to exclude the participation of taste buds on the lips. This agrees with the anatomical findings of Miss Clapp ('99) whose careful study of the skin of this fish failed to reveal any terminal buds on these appendages or elsewhere away from the buccal cavity. A jet of sea water directed against these appendages or the body surface in general usually disturbs or frightens the animal merely, if it is noticed at all. A jet of clam juice similarly applied calls forth the same reaction unless it is so directed as to reach the lips, in which case the fish reacts to it just as the hake and tom cod do, attempting to take the tip of the pipette in the mouth. The following solutions were applied in the same way by a fine pipette to various parts of the body surface: 0.2% hydrochloric and 1% hydrochloric acid in sea water, and 0.1% quinine sulphate in sea water. In all cases the fishes paid no attention to the stimulus unless the substance was so applied as to come into contact with the lips. The experiments lead me to conclude that the toad fish can taste only within the mouth and on the lips and that if the cutaneous appendages have any sensory function it is tactile only.

CONCLUSION.

The morphological and physiological significance of the terminal buds of fishes is a problem which has exercised some of the ablest morphologists for over half a century. The methods of the older anatomy have signally failed to yield concordant results. Not until the innervation of the cutaneous sense organs was worked out from the standpoint of nerve components was their confusion relieved. The older morphologists (Schulze, Merkel and others) discovered a morphological criterion, the "hair cells," by which the terminal buds could be distinguished from cutaneous sense organs belonging to the lateral line system. But this fact attained its significance only when it was discovered that the organs of the lateral line system, or neuromasts, which possess the "hair cells" are always innervated by lateralis nerves related centrally to the tuberculum acusticum, while terminal buds, which lack the "hair cells," are always innervated by communis nerves which are related centrally to the primary gustatory centers of the vagal and facial lobes.

Presumably, then, lateral line organs and terminal buds have different functions, and further the function is probably not tactile in either case, since all parts of the skin receive general cutaneous nerves in addition to the special sensory components and these general cutaneous nerves are related proximally to different centers from either of the others. The lateral line organs are known to be used in the maintenance of bodily equilibrium and the perception of mass motion of the water (compare the recent works of Lee and Parker). On the other hand, the terminal buds are related in structure and innervation to undoubted taste buds of the mouth and hence the inference that their function is taste. This inference is abundantly confirmed by the experiments here recorded; and the function and morphological rank of the terminal buds are at last definitely fixed.

It may be regarded as established that fishes which possess terminal buds in the outer skin taste by means of these organs and habitually find their food by their means, while fishes

which lack these organs in the skin have the sense of taste confined to the mouth. The delicacy of the sense of taste in the skin is directly proportional to the number of terminal buds in the areas in question.

Numerous unrelated types of bony fishes from the siluroids to the gadoids which possess terminal buds have developed specially modified organs to carry the buds and increase their efficiency. These organs may take the form of barblets or of free filiform fin rays. The free rays of the pelvic and dorsal fins of gadoid fishes are thus explained, and indeed this is possibly the motive for the migration into the jugular position of the pelvic fins of the gadoids.

In all cases where terminal buds are found on barblets or filiform fin rays gustatory nerves belonging to the communis system are distributed to them. These barblets and free fin rays likewise receive a very rich innervation of tactile or general cutaneous nerves, so that they merit their popular designation, "feelers." Both sets of end organs undoubtedly cooperate in the discrimination of food and the animal has the power of very accurate localization of the stimulus. Whether the gustatory stimulus alone can be localized apart from its tactile accompaniment cannot at present be stated. A purely tactile stimulus with no gustatory element can be localized precisely and I have as yet no conclusive evidence that a pure gustatory stimulus even when strong, can be located by the fish. It is certain that feeble and widely diffused gustatory stimuli cannot be accurately located by the fishes which I have experimented with either by the terminal buds or by any other organs.

The fishes in which the cutaneous terminal buds are most highly developed are in general bottom feeders of rather sluggish habit and in some cases they are nocturnal feeders. The high development of this sense is compensated for in some fishes by the reduction of others. The visual power of the fishes is especially apt to suffer degradation. This degradation may be organic, a positive degeneration of the visual apparatus, as in *Ameiurus*, or it may be merely functional. In the latter

case, though the organs of vision are not necessarily modified, these organs are actually used in procuring food, the fish being unable to effect visual reflexes toward food substances or to correlate visual stimuli with the movements necessary to react toward food substances. The fish may be perfectly able to effect other visual reflexes, but is apparently unable to understand the significance of food when perceived by the sense of sight only. This particular central reflex path has never been developed, or has atrophied from disuse. Nature has here effected for the species something similar to what is accomplished in individual men occasionally by disease, in the production of certain aphasias.

The number of reflex activities habitual to an animal with a nervous system as simply organized as the bony fish is probably far smaller than is commonly supposed, and these activities are in general characterized by but little complexity of organization. It is probably quite within the range of possibility to determine by observation and experiment for any given species of fish to a high degree of accuracy what these habitual activities are and to work out by histological methods the reflex arc within the nervous system for each of them; and since the human nervous system is built up on the same general plan as the piscine nervous system it follows that such a thorough and systematic correlation of function with structure would be profitable from many points of view.

Terminal buds do not occur in the outer skin of all fishes; in fact, they are probably lacking here in the greater number of species. But whenever they do occur they tend to be arranged according to one general plan. This is particularly true of their nerve supply, for, though the details of the peripheral nerves of fishes are exceedingly diverse, yet the main communis branches for terminal buds, when such occur, are substantially similar from the *Siluridae* to the *Gadidae*. There are, however, striking resemblances in detail between the siluroids and the cyprinoids which are much more significant of close relationship. Both groups are characterized by an extreme development of the system, reaching generally over the whole body

surface; in both cases the peripheral communis nerves correspond to the general teleostean type, though with a remarkable modification of the recurrent branch of the facialis in the case of the cyprinoids; and finally the communis centers in the medulla oblongata differ from those of all other teleosts in that there is developed a facial lobe as well as a vagal lobe in the primary central gustatory center. The facial lobe (the so-called lobus trigemini of siluroids and the "tuberculum impar" of cyprinoids) in both cases receives by way of the communis root of the facialis the nerve fibers from all of the terminal buds of the outer skin, while the vagal lobe is reserved for those from the mouth and viscera. This emphasizes from a new point of view the close relationship between these two groups of fishes, as recognized by the systematists generally.

Though the *Ostariophysi* may have had a different origin from that of the other teleostean orders, yet the resemblances in general plan of the terminal bud system of sense organs in this group and in the other orders make it improbable that this system has arisen independently and followed a parallel development in the two groups of fishes. Its phylogenetic origin must therefore be sought among the ganoids, and until we have more exact information concerning the nerve components and sense organs of these fishes further speculation in this direction is idle.

This study has been directed primarily toward the solution of a simple physiological problem; but in a purely incidental way some points of interest to comparative psychology have come up. We have seen that in the cat fish, hake and tom cod the reflex of seizing the food is normally set off by a combined stimulus of tactile and gustatory end-organs. At first the fish may react similarly to a pure tactile stimulus and the tactile plus the gustatory. After a brief training, however, he acquires the ability to discriminate between the former, which is never followed by satisfaction, and the latter, which is followed by the pleasure of feeding. Clearly the fish learns by experience. We find also some differences between the different species of fishes in this respect, depending on the relative impor-

tance of the tactile and gustatory elements of the sensation complex in the normal reflex life of the fish.

It would be interesting to inquire the part played by memory in these reactions. In the case of Ameiurus, where the tactile and gustatory elements of the reflex of seizing food can be experimentally isolated by training, it would doubtless be possible to measure quantitatively the duration of the persistence of this acquired discrimination. I have made no accurate observations on this point, but can say in general that the memory of these fishes seems to be fairly good. (By the term memory I do not mean to prejudice the question of the part played by consciousness here. The original reaction may be largely or wholly an unconscious or automatic response and the "memory" may be an organic memory more closely allied to habit.) At the beginning of the tests with cotton the cat fishes generally seized the cotton just as they did the meat. At the close of the first day's experiments they had learned to ignore the cotton as a rule, and half an hour after the close of this series of tests they still would pay small attention to the cotton; but by the day following, if tested first with meat, they would take the cotton for a few times or would react to it slightly during the first few tests, but would learn to let it alone sooner than on the first day. But toward the close of the experiments after several weeks of practice I rarely got any reaction at all with the cotton under any circumstances, even if the fishes had not been tested for several days. With the gadoids the number of experiments was much smaller and they were continued for a shorter time, but I never got so good evidence of memory of the discrimination. On successive days the tests were much alike. The inability of the tom cod to remember to ignore a tactile contact which is not followed by satisfaction so long as the cat fish remembers a similar discrimination I take to be an indication that the tactile element plays a much larger part in the reflex complex in the gadoids. The known distribution of the terminal buds favors this view also, for while they are very abundant on the barblets and body of the cat fish they are rather sparse on the free fins of the gadoids and the general cu-

taneous nerve supply on the fins of these fishes is greatly in excess of the communis nerve supply.

I noticed also that all of the fishes that ate freely in captivity soon accustomed themselves to novel methods of feeding and in the case of the cat fishes and the hake especially, as soon as I approached their tanks after the experiments had been in progress some time, the fishes would rise to the top of the tank and eagerly await the expected food. This restlessness became so great with the cat fish that the experiments became increasingly more difficult and there was evidence that vision and possibly smell assumed greater importance after this expectation of food had made its appearance.

Denison University,
Dec. 15, 1902.

LITERATURE CITED.

ALLIS, E. P., JR.
'97. The Cranial Muscles and Cranial and First Spinal Nerves in Amia calva. *Journ. Morph.*, XII, 3.

BATESON, W.
'90. The Sense Organs and Perceptions of Fishes, with Remarks on the Supply of Bait. *Journ. Marine Biol. Assoc., London*, vol. I, pp. 225-256.
'90 *a*. Sense of Touch in the Rockling, *Ibid.* p. 214.

CLAPP, CORNELIA M.
'99. The Lateral Line System of Batrachus tau. *Journ. Morph.*, XV. 2.

GRABER, V.
'85. Vergleichende Grundversuche über die Wirkung und die Aufnahmstellen chemischer Reize bei den Tieren. *Biol. Cent.*, Bd. V., Nos. 13, 15, 16.
'89. Ueber die Empfindlichkeit einiger Meertiere gegen Riechstoffe. *Ibid.*, Bd. VIII, pp. 743-754.

GÜNTHER, A. C. L. G.
'80. An Introduction to the Study of Fishes, *Edinburgh.*

HARRIS, WM. C.
'02. Salmon and Trout. American Sportman's Library. *N. Y., The Macmillan Co.*

HERRICK, C. JUDSON.

'99. The Cranial and First Spinal Nerves of Menidia; A Contribution upon the Nerve Components of the Bony Fishes. *Journ. of Comp. Neur.*, Vol. IX, pp. 153-455.

'00. A Contribution upon the Cranial Nerves of the Cod Fish. *Ibid.*, X, 3.

'01. The Cranial Nerves and Cutaneous Sense Organs of the North American Siluroid Fishes. *Ibid.*, XI.

JOBERT.

'72. Etudes d'Anatomie Comparée sur les Organes du Toucher chez divers Mammifères, Oiseaux, Poissons et Insects. *Ann. sc. nat.*, 5 Ser., T. XVI.

KAHLENBERG, L.

'98. The Action of Solutions on the Sense of Taste. *Bul. Univ. of Wisconsin, Science Series*, vol. II, pp. 1-31.

LEE, FREDERIC S.

'92. Ueber den Gleichgewichtssinn. *Centralbl. f. Physiol.*, Bd. 6, S. 508-512.

'93. A Study of the Sense of Equilibrium in Fishes. *Jour. of Physiol.*, Vol. 15, pp. 311-343.

'94. A Study of the Sense of Equilibrium in Fishes, Part II. *Jour. of Physiol.*, Vol. 17, pp. 192-210.

'98. The Functions of the Ear and the Lateral Line in Fishes. *The Amer. Jour. of Physiol.*, Vol. 1, pp. 128-144.

LEYDIG, FR.

'51. Ueber die äussere Haut einiger Süsswasserfische. *Zeits. wiss. Zool.*, III.

'79. Neue Beiträge zur anatomischen Kenntniss der Hautdecke und Hautsinnesorgane der Fische. *Festschr. z. 100 Jähr. Naturf. Ges. zu Halle.*

'94. Integument und Hautsinnesorgane der Knochenfische. Weitere Beiträge. *Zool. Jbr. Abt. f. Anat. u. Ontogen.*, VIII, 1, pp. 1-152.

LINTON, E.

'01. Parasites of Fishes of the Woods Hole Region. *Bul. U. S. Fish Com. for 1899.*

MERKEL, FR.

'80. Ueber die Endigungen die sensiblen Nerven in der Haut der Wirbelthiere. *Rostock.* Contains extensive bibliographies.

MORRILL, A. D.

'95. The Pectoral Appendages of Prionotus and their Innervation. *Journ. Mophology*, XI.

NAGEL, W. A.

'94. Vergleichend physiologische und anatomische Untersuchungen über den Geruchs- und Geschmackssinn und ihre Organe, mit einleitenden Betrachungen aus der allgemeinen vergleichenden Sinnesphysiologie. *Bibliotheca Zoologica, Stuttgart*, Heft 18. Contains a bibliography of 335 titles.

PARKER, G. H.

'03. Sense of Hearing in Fishes. Abstract of a paper read before the Am. Assoc. for the Advancement of Science. *Science*, N. S., Vol. XVII, No. 424.

'03 *a*. The Sense of Hearing in Fishes. *Am. Naturalist*, XXXVII.

'03 *b*. Hearing and Allied Senses in Fishes. *Bull. U. S. Fish Commission for 1902.*

RICHARDS, T. W.

'98. The Relation of the Taste of Acids to their Degree of Dissociation. *Am. Chemical Journal.*

SCHULZE, F. E.

'63. Ueber die becherförmigen Organe der Fische. *Zeits. f. wiss. Zool.*, XII, 2.

'67. Epithel- und Drüsenzellen. *Arch. f. mikr. Anat.*, III.

'70. Ueber die Sinnesorgane der Seitenlinie bei Fischen und Amphibien. *Arch. f. mik. Anat.*, VI.

STANNIUS, H.

'49. Das peripherische Nervensystem der Fische, anatomisch und physiologisch untersucht. *Rostock.*

TODARO, F.

'73. Les organs du goût et la muqueuse bucco-branchiale des sèlaciens. *Arch. Zool. Expérim.*, II, pp. 534-558.

WEBER.

'27. Ueber das Geschmacksorgan der Karpfen. *Meckel's Archiv f. Anat.*

WHITMAN, C. O.

'99. Animal Behavior. Biological Lectures, Woods Hole, Session of 1898. *Boston.*

ZINCONE, A.

'78. Osservazioni anatomiche su di alcune appendici tattili dei pesci. *Rend. Accad. Napoli*, XV.

ADDENDUM.

During the winter and spring of 1903 some further observations have been made with the purpose of answering (among others) the question raised above, whether fishes can localize a sensation received by the terminal buds alone with no tactile accompaniment, or, in other words, whether gustatory sensations may be provided with a local sign as tactile sensations are. (This question, of course, does not necessarily involve the more general one as to the essential nature of the local sign, whether it is due to a "specific energy" of the peripheral nerve or sense organ or to central differentiation in the terminal nucleus.)

Some recent clinical observations suggest that in human beings such a localization of gustatory sensations is possible.

CUSHING (*Johns Hopkins Hosp. Bull.*, XIV, No. 144, 1903, p. 77) reports after destruction of the Gasserian ganglion and total paralysis of general sensation on the anterior part of the tongue. that the gustatory sensibility remains unimpaired and that in this case the gustatory sensations can be localized.

It is not, however, absolutely certain that it is the gustatory fibers which effect the localization, for the chorda tympani, which was uninjured, may carry also a certain number of fibers for general sensation from the facialis root in addition to gustatory fibers, as CUSHING assumes is the case with the chorda from some of his results and from those of KÖSTER.

My own observations were made on the young of Ameiurus from five to eight cm. long, received from the state fish hatchery at London, O., in October, 1902, and kept under observation in tanks during the following winter. These fishes prove to be more shy and less teachable than the smaller Ameiurus fry (about three cm. long) hatched by wild parents upon which the experiments reported in the preceding pages were made.

I have verified upon these fishes most of the observations made on the smaller fishes last year. The most noticeable difference in their behavior is the evidently greater visual power in these fishes. As soon as they began to feed freely in the

presence of the observer (which required several months of training) they began to show evidence of visual recognition of a moving bait, if very near them, and provided they had just previously been fed with the same food in the same way. They never under any circumstances notice visually a still bait and their recognition of a moving bait is at best very imperfect and only an occasional occurrence.

Upon putting a concealed bait in a tank with the fishes I found no evidence that they are able to locate it by the sense of smell or otherwise from a distance, provided the water is still. If, however, they swim near enough to the capsule containing the bait (beef liver, cheese, etc.) to pass the barblets into the strong diffusion currents emanating directly from the bait, it is located instantly. The reactions here are essentially like those by which the tom cod localizes a concealed bait, though I have not completed the experiment by extirpation of the nose to determine what part, if any, is played by the sense of smell. So far as my experiments have gone, these fishes will not locate a concealed bait in still watër until they pass within 5 cm. of it.

In running water, however, the case is quite different. I constructed a long, narrow tank, so arranged that a slow stream of water can pass through it from end to end. By covering the lower end of the tank and illuminating moderately the upper end, it can be so arranged that the negative phototaxis will counteract any positive rheotaxis and the fishes will remain in the lower end of the tank. If now liver or other strong bait is placed above them, the fishes will promptly swim up the current and locate the meat.

The experiments seem to indicate that concealed food cannot be located by these fishes from a distance in quiet water (cf. NAGEL, '94); but that if the fish passes within a few centimeters of it the diffused juices are recognized and the food located promptly. In running water, however, the fish will follow the diffused juices up the stream for considerable distances and so find the food—a fact well known to every fisherman. Tactile sensations are clearly not involved; it lies between the

senses of smell and taste, and I have not as yet gone far enough with this series of experiments to decide finally the part played by smell.

I have, however, tested the sensitiveness of the barblets to diffused savors more fully. Raw meat or beef liver was minced, extracted in a little water and strained. A wisp of cotton was wound on the end of a slender wire, dipped in the meat juice and gently lowered so as to lie a few millimeters from the tip of a barblet of a cat fish which was otherwise entirely concealed under a large leaf. The fish was unable to see the cotton and actual contact with the barblet was carefully avoided. Within a few seconds the fish becomes conscious of the savor and turns *toward the cotton.* Again, I filled a glass tube of about 3 mm. bore with meat juice, closed the upper end with the finger and carefully lowered the open end down over a projecting barblet, as in the previous case. The specific gravity of the meat juice is slightly greater than that of the water and from the lower end of the tube (the upper end being kept closed) the juice slowly diffuses downward enveloping the tip of the barblet, without, however, any noticeable current being produced in the water. The fish locates the stimulus and turns towards the source of it. In other cases I colored the juice with a little blood, so that the course of the diffusion currents could be observed, and it is evident that the reaction follows the stimulus of the *barblet* only, and not the organ of smell, for the movement is made before the diffusion currents have had time to reach the nostril.

These reactions are not as prompt or precise as those given after *contact* with a sapid substance where a tactile sensation accompanies the gustatory, and in a large percentage of the cases there is no definite reaction toward the point stimulated but merely the more vague "seeking reaction" to which reference has been made above. Nevertheless they indicate on the whole that pure gustatory stimuli, if very strong and applied to a small area of the percipient organ, *can be localized in space, or have a "local sign."*

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COPPER-BEARING ROCKS OF VIRGILINA COPPER DISTRICT, VIRGINIA AND NORTH CAROLINA.

By THOMAS LEONARD WATSON

Granville, Ohio, July, 1903.

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Introduction.

Some time was spent during the month of August, 1901, in a field examination of the Virgilina copper district, and the specimens of the rocks and ores collected were subsequently studied in the laboratory. Study was principally confined, both in the field and laboratory, to the rocks of the area, to determine their nature and origin. The ores were given only secondary consideration.

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[1] The author is under special obligations to Professor J. Morgan Clements, of the University of Wisconsin, for kindly reading and criticising this paper in manuscript, and he is indebted to Mr. W. H. Pannebaker, of Virgilina, for the photographs illustrating it.

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The rocks have been designated slates by the earlier workers, which, according to present usage, would imply a metamorphosed sediment. In many instances the characteristic field appearance of the rocks is that of slate or schist, but in their altered phases they are shown, by structural, chemical, and petrographic evidence, to be igneous in origin. Their subsequent alteration developed a schistose structure and an abundance of chlorite, epidote, and a limited quantity of hornblende. These impart to the rock its uniform green color and give the popular name "greenstone."

Recent workers are agreed as to the igneous origin of these rocks, and in a recent paper discussing the type of metalliferous deposits of the area Weed[1] has correctly named the rocks.

Scattered areas of ancient volcanic acid and basic rocks are described by Williams[2] and Nitze[3] immediately to the southwest of the Virgilina district. The rock areas are found in Orange, Chatham, Montgomery, Randolph, and Stanly counties, North Carolina. Nitze describes the basic rocks as being dark green in color, partly massive and partly schistose in structure, and perhaps pyroxenic and at times propylitic in mineral composition. I have not visited these areas, but the descriptions of the basic rocks denote similarity to the Virgilina greenstones.

This paper discusses the evidence for regarding the Virgilina area as one of greatly altered pre-Cambrian volcanic rocks, closely allied to similar areas of ancient volcanics distributed along the Atlantic coast from eastern Canada to Georgia, and certain altered basic rocks in the Lake Superior region. The time which the writer was able to give to this investigation was insufficient to map and define the exact limits of the area.

Previous Work.

The rocks of this immediate area have hitherto received but little attention. No detailed work with respect to the dif-

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[1] Trans. Amer. Inst. Min. Engrs., Vol. XXX, p. 453 et seq.

[2] Journal of Geology, 1894, Vol. II, pp. 1-31.

[3] Bulletin No. 3, N. C. Geol. Survey, 1896, pp. 37-43; Bulletin No. 10, ibid, 1897, pp. 15, 16

ferentiation and classification of the rocks of the Virgilina district has yet been undertaken. Brief references of a general character dating as far back as the Emmons Survey (1856) are found in numerous reports on economic subjects issued by the North Carolina Geological Survey. Such references as bear directly on the area in question are here reviewed:

After describing the Gillis copper mine in Person county, North Carolina, the earliest discovered one in the belt, Doctor Emmons[1] refers to the rock as follows: "The rock immediately investing the mine is the altered slate belonging to the Taconic system." Emmons first thought the rock was talcose, but later regarded it as argillaceous.

Professor Kerr[2] makes no special mention of this individual area in his report on the geology of North Carolina, but in defining the "Huronian" rocks of the state he groups the area as the northernmost limit of a belt of Huronian rocks traversing the state in a northeast-southwest direction. Speaking in a general way of the rocks composing the Huronian belt, Kerr mentions the following types: "Quartzite, clay slates, gray, light-colored and drab and greenish." "At some points the quartzites are argillaceous, and at others a few miles west of Smithfield it approaches a fine conglomerate. The clay slates are occasionally slightly hydro-micaceous." He mentions dikes of diabase and dolerite as being common over parts of Granville county. Professor Kerr refers the rocks of certain parts of Granville and Person counties to the lower Laurentian. He mentions the "characteristic and prevalent rocks as being syenite, dolerite, greenstone, amphibolite, granite, porphyry and trachite."

In a geological map of North Carolina, accompanying a report by Kerr and Hanna in 1887, the Person-Granville county area is grouped as the northernmost part of the Huronian.[3] A section given at the bottom of the map, extending from the

[1] Geology of the Midland Counties of North Carolina, 1856, p. 344.

[2] Geology of North Carolina, 1875; Vol. I, pp. 123, 124, and 131.

[3] Map accompanying "Ores of North Carolina," 1898.

Tennessee line to Newberne, North Carolina, designates the rocks of the copper belt area as "Huronian slates."

Mr. Hanna[1] describes the copper belt in Person and Granville counties in detail from the standpoint of economic mineralogy. He designates the rocks as schists and slates, and regards them as decidedly chloritic rather than argillaceous, as described by Emmons. Hanna gives the following quotation from a report by Dr. Jackson.

"The strata are occasionally disrupted by dikes; about half a mile from the Gillis, and dipping eastward to it, is a dike bearing N. 20 E., containing abundant sprigs and grains of disseminated native copper. Epidote occurs both in the trap rock and in the quartz, and in the slate strata near the dike, which seems to indicate that the trappean rock is of the same geological age as the quartz veins."

Mr. Lewis[2] describes areas of medium fine and compact grain biotite granites, occurring immediately to the east of the copper belt proper, in Granville and adjoining eastern counties.

In his description of the iron ore deposits in the northwestern part of Granville county, Mr. Nitze[3] makes the following reference to the rocks: "Geologically they [iron ores] occur in the crystalline slates and schists, . . . lying conformably between slate walls. . . . " He further mentions small crystals of magnetite occurring in gray micaceous schist coated with malachite.

Nitze and Hanna[4] mention in "Gold Deposits of North Carolina" the principal copper mines in the copper belt, giving assays of the ores and describing in some detail the topography and general geologic features. They designate the rock as schist.

Pages 37 to 43 of the same report describe the occurrence of ancient acid volcanics found in the same belt, but directly south-

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[1] Ores of North Carolina, 1888, p. 215.

[2] Notes on Building and Ornamental Stones, First Biennial Report, N. C. Geol. Survey, 1893, p. 75.

[3] Iron Ores of North Carolina, N. C. Geol. Survey, Bulletin No. 1, 1893, p. 47; Engineering and Mining Journal, 1892, Vol. 53, p. 447.

[4] Gold Deposits of North Carolina, N. C. Geol. Survey, Bulletin No. 3, 1896, p. 52.

west of the Virgilina area. The scattered areas lie principally in Chatham and Orange counties, within short distances of Raleigh and Chapel Hill. The close resemblance of certain ones in structure and composition to the rhyolites of South Mountain in Pennsylvania is noted. The localities were visited by Professor George H. Williams, in company with Professor J. A. Holmes, in the summer of 1893, and afterward discussed in the Journal of Geology for 1894 by Williams.[1] They are referred to as pre-Cambrian in age, and are suggested as probably being contemporaneous with the somewhat analogous rocks of the South mountain, in Maryland and Pennsylvania.

In describing the Carolina Gold Belt area, situated in the central Piedmont region and crossing the central part of the state in a southwesterly direction, Nitze and Wilkens[2] again refer to the kinds and distribution of the ancient volcanic rocks. Their description follows:[3]

"The volcanic rocks occupy irregular patches along the eastern border of the belt, in close proximity to the western edges of the Jura-Trias basins. They comprise both acid and basic types. The acid rocks are generally devitrified to such an extent that their real character is no longer recognizable to the naked eye, and they appear as ordinary cherts or hornstones, although flow structure is at times still discernible. Microscopic examination shows them to belong to the class of rhyolites and quartz porphyries. They are sometimes sheared into schists, as for instance at the Haile mine, South Carolina. The basic types are dark green in color and perhaps pyroxenic in composition; they are sometimes massive porphyrites, but more generally sheared into schists. The pyroclastic breccias consist of angular fragments of the acid rhyolites and porphyries in a basic matrix. The age of these ancient volcanics is believed to be pre-Cambrian. They seem to be analogous to, and probably contemporaneous with, similar rocks of the South mountain in Maryland and Pennsylvania, and other points along the Atlantic coast."

Professor George H. Williams[4] published in 1894 a very important paper on the distribution of the ancient volcanic rocks along the Atlantic Coast region. Attention is directed

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[1] Journal of Geology, 1894, Vol. II, pp. 1–31.

[2] Gold Mining in North Carolina, et cetera, N. C. Geol. Survey, Bulletin No. 10, 1897, pp. 15, 16.

[3] Ibid., p. 16.

[4] Journal of Geology, 1894, Vol. II, pp 1–31.

in the paper to the area immediately southwest of the Virgilina district, in which occur both acid and basic eruptives, mostly acid, of pre-Cambrian age.

Mr. W. H. Weed[1] recently published a valuable paper treating in some detail the type of ore deposits in this belt and the important economic features. He refers to the rocks of the district as follows:

"The country-rock is schist, in a few places massive enough to be called gneiss. . . . The rocks are all of igneous origin—even the softest and most shaly show this character in thin sections under the microscope. But in a few instances only is the igneous nature of the schists recognizable to the eye. This was observed at the Thomas mine, where a purplish rock is clearly a porphyritic meta-andesite. These schists are cut by dikes of later igneous rock (diabase). The only one seen by the writer was that exposed in the Blue Wing mine. . . . Apart from the dykes, however, I would say, on the strength of field-observations alone, that the rocks are of igneous origin, and belong to the various porphyries which have been discovered in the Appalachian belt This conclusion is confirmed by the microscopic examination of thin sections, which has shown the rocks to be altered andesites, that is meta-andesites and andesite tuffs."

General Field Characters and Occurrence.

As seen from the accompanying map, the area is located near the eastern border of the Piedmont plain, in Halifax county, Virginia, and Person and Granville counties, in North Carolina, 47 miles east of Danville. The belt occupies a low, flat-topped, though somewhat conspicuous, ridge, which trends a few degrees west of south and slopes very gradually to the east and west. It will average 100 to 200 feet in elevation above the neighboring stream valleys. The cross-drainages are all small, but the ridge is flanked by several large ones on the west and northwest sides. The ridge is traced northward to the Dan River valley, in Virginia, some 10 miles north of the state line. In North Carolina its southward extension is estimated by Hanna[2] to be about 30 miles, reaching nearly to Durham. Prospecting is confined, however, to an approxi-

[1] Types of Copper Deposits in the Southern United States, Trans. Amer. Inst. Min. Engrs., 1901, Vol. XXX, pp. 453, 454.

[2] Ores of North Carolina, Raleigh, 1888, p. 215.

mate north-south distance of 18 miles along the ridge and to an average cross-distance of from 2 to 3 miles. Although of no conspicuous height, the ridge forms a somewhat prominent feature in the landscape.

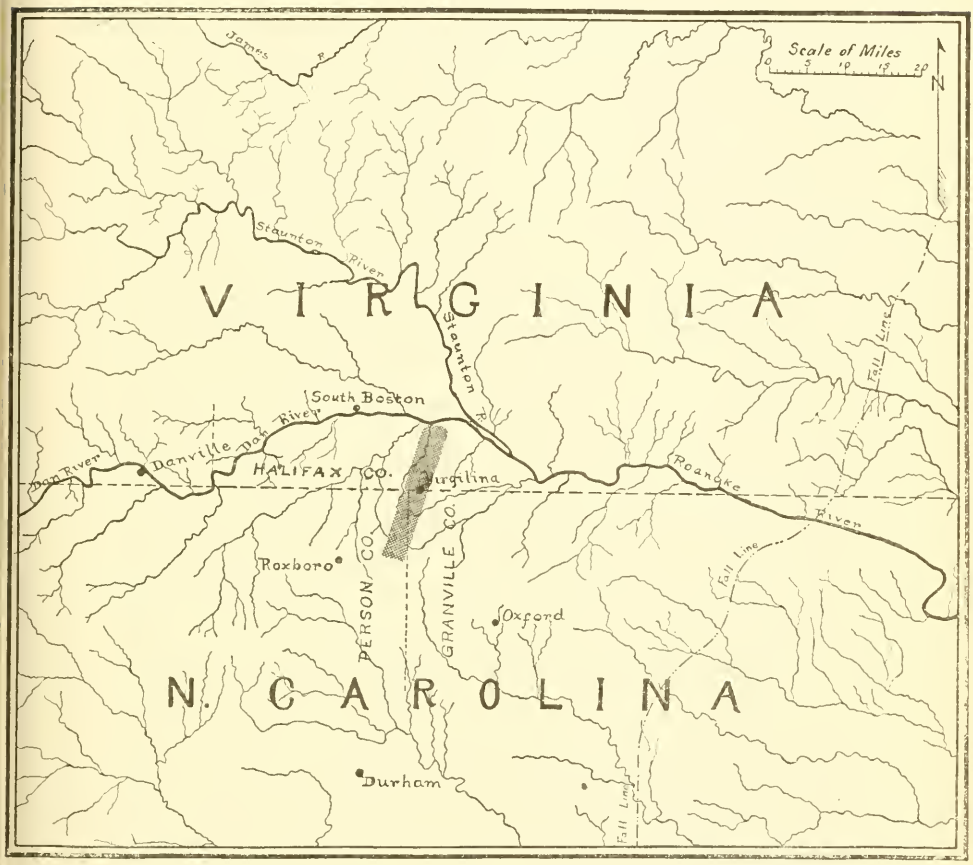

FIGURE 1.—*Virgilina Copper District, Virginia and North Carolina.*
Copper district indicated by shaded area.

Natural outcrops of the rock are by no means common and are seldom more than 3 feet high, forming sharp and narrow spurs or reefs, which persist for only short distances. The numerous shafts sunk over the greater part of the belt to depths of 40 to 500 feet afford excellent opportunity for exceptional collections of the rocks and ores.

The covering of loose, decayed surface rock and soil is very thin, and the moderately fresh and firm rock is encountered at slight depths beneath the surface.

At the mine openings some alteration in the vein constituents is indicated to the entire depth of the workings, 400 to 500 feet. This is shown in the case of the sulphide ores, which in several places are slightly changed by the percolating carbonated waters to the green copper carbonate (malachite) found slightly staining the vein material and the unaltered ores. The rocks taken at these depths are of the same characteristic green color, and the thin-sections indicate the same amounts of chlorite and epidote as those from the shallow depths. As developed, both macroscopically and microscopically, the rocks collected at the various depths are indistinguishable. This is also shown in the dumps at the mine openings.

The microscope reveals, as elsewhere shown, the igneous origin of the rocks; but, with few exceptions, the rocks do not entirely indicate their true igneous nature in the field. They are prevailingly finely laminated and schistose in structure, having the general characteristic features of a soft, green to purple colored schist. A number of sections showed the prevailing strike of the schistosity to be north 10 to 20 degrees east and an eastward dip of 70 to 80 degrees.

The change in these rocks is clearly the result primarily of the processes of metamorphism active while the rocks were deeply buried. At a subsequent date, when the rocks were brought near the surface, they were further changed by weathering. The mineral products resulting from the alteration are strongly in evidence. Epidotization and chloritization are manifested on a considerable scale.

The greenstones are cut in several places by diabase dikes of later geological age. One of these dikes, 12 feet wide, is exposed in the Blue Wing mine at the 100-foot level, where it is observed to cut across the schistosity of the rocks. These dikes are described in the reports of the North Carolina Survey as being quite numerous in parts of Granville and Person coun-

ties. Faulted and slickensided surfaces are in evidence at some of the mine openings.

The rocks are further cut by numerous irregular quartz veins, which contain the workable copper ores. The veins are traced for a mile or more in length on the surface, and in most cases they are more or less parallel, partially overlapping at the ends, and trending north 5 to 10 degrees east. They are grouped by Weed[1] as true fissure veins, lenticular in shape, though connecting, crossing at times the schistosity of the rocks and at others parallel to it. The surface over most of the district is much littered with white quartz fragments derived from the disintegration of the veins.

PETROGRAPHY.

Macroscopic Descriptions.

A pronounced schistose structure prevails, and only in a few places do the rocks appear like massive eruptives in the field. The degree of schistosity varies from the thin banding of a gneiss to the typical foliation of micaceous schists. The very finely banded structure is more characteristic of the purple-colored rocks. The rocks vary in color from some shade of medium to dark green (the prevailing color) to a slate purple.

The rocks are aphanitic in texture, displaying at times a distinct porphyritic structure in the massive phases, which becomes more apparent under the microscope. The massive phases of the rock are indicated at several places within a few miles to the north and south of the town of Virgilina. With one exception, this type is prevailingly dark in color, showing on close examination a mingling of green and purplish shades, with the greenish tint so predominant that the rock appears dark green on first glance. Both the characteristic chlorite and epidote shades of green are contrasted at times in the same specimen. On a freshly broken surface the fracture is conchoidal to subconchoidal, with a more or less waxy luster.

Approximately half a mile south of Virgilina a shallow

[1] Trans. Amer. Inst. Min. Engrs., 1901, vol. xxx, p. 452.

opening (Cornfield) is made, showing the massive rock in its least altered condition (analysis I). The rock is porphyritic in structure and the color is a medium dark-purplish shade, which contrasts with the surrounding more altered green schistose rock.

Epidote of the usual pistachio-green color enters largely in places into the composition of the rocks, and it is mixed locally in considerable proportion with white quartz as a vein mineral. The schistose greenstone is easily scratched with the knife, and suggests approximately the same degree of hardness as that of ordinary clay slate.

At the Copper World mine, 6½ miles south of Virgilina, in the Carolina portion of the belt, a partially loose-textured, fine-grained, purple rock is mixed with the surrounding green schists. The material bears every resemblance to a tuff,[1] and is streaked in places by the characteristic actinolite shade of green due to alteration, and contains inclosures of a dark-colored massive material, usually of small but varying dimensions and partially rounded in outline. The fragmental or clastic nature of the mass is plainly visible. The microscope confirms the clastic nature of this rock and shows that it is composed of fragments of igneous rocks of the same character and composition as the igneous rocks of the district. Microscopic study also indicates the presence of similar clastic material at a number of other points in the district.

No trace of the amygdaloidal structure, so characteristic of the South Mountain and Lake Superior basic greenstone areas, has been observed in the Virgilina rock.

Microscopy of the Rocks.

The rocks vary in texture from dense aphanitic to medium fine-grained, with the porphyritic structure shown usually in the massive types. The original minerals are entirely altered to secondary minerals in many of the sections, but, with few exceptions, some trace of the original outline of the feldspar con-

[1] See Weed, W. H., op. cit.

stituent is shown and more or less of the original rock texture preserved. While this is true for the feldspar constituent, the original bisilicate constituent is completely altered in every slide studied, without any indication as to what the mineral originally was. Considering the age and composition of the rocks, it seems remarkable that any of the original minerals or structures should be preserved at present. When shown, the texture varies from a partial microophitic to microlitic in the non-phorphyritic types, with the same variation and composition of the groundmass in the porphyritic rocks denoted.

The constituents present are plagioclase, bluish to light green amphibole, chlorite, epidote, zoisite, calcite, iron oxide (partly magnetite), quartz, and apatite. Of these only the feldspar, a part of the iron oxide (magnetite), and apatite are original. Both chlorite and epidote, intimately associated with more or less hornblende, are abundantly developed in most of the sections, sometimes one, sometimes the other predominating; but the two are at all times intimately connected.

In the porphyritic and non-porphyritic types the feldspar is present as lath-shaped crystals, showing the broad twinning lamellæ of the albite type. Twinning after the Carlsbad law was observed in several instances. In the ground mass of the porphyritic rocks and in the fine-textured non-phophyritic types the feldspars are microlitic, with the boundaries less sharp and well defined than for the lath-shaped feldspars, and the twinning is not at all or only slightly indicated. Sometimes the feldspar grouping is suggestive of the sheaf-like arrangement described by Clements[1] in similar volcanic rocks of the Hemlock formation of Lake Superior. Poikilitic texture is well developed in many of the larger feldspar laths.

Feldspar is the only porphyritically developed mineral, and it consists of fairly large, stout laths of broadly striated plagioclase, with maximum extinction angles measured on the twinning planes of 14 to 20 degrees, which would apparently indicate an acid plagioclase, probably near oligoclase.

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[1] Monograph No. xxxvi, U. S. Geol. Survey, 1899, p. 99.

The feldspars of both the groundmass and phenocrysts are frequently fractured and mashed, showing the effects of pressure, which is seen to best advantage in the schistose rocks.

Not a trace of original hornblende was positively identified in any of the sections. Amphibole is fairly abundant in most of the slides as a secondary product, and as such is usually light green to slight bluish green in color and as fibrous and frayed out masses. A more common occurrence, perhaps, is as a felt of actinolite needles admixed with the other constituents, particularly chlorite, epidote, and iron oxide. The needles are very long and slender and are frequently much curved and bent. The pleochroism of the actinolite is usually quite strong.

No trace of either augite or olivine was indicated in any of the slides. On account of the greatly altered condition of the rocks, it would not be safe to state that they were not present as original constituents.

Chlorite is a constant and abundant constituent of the rocks, but is variable in amount, and presents the usual occurrence for such rocks. A striking feature is the intimately associated grains and plates of epidote distributed through the chloritic mass in a manner to indicate the simultaneous development of the two minerals, a characteristic occurrence in some of the Lake Superior greenstones described by Williams.[1] Clements[2] has shown that in some of the basic vocanics of the Hemlock formation the great abundance of chlorite in some sections is more than could result from the alteration of that amount of the original bisilicate present, and points out that it is derived in part from the altered glassy base. This explanation is likely applicable to some of the sections of the Virgilina rocks, since the amount of chlorite is in excess of the original bisilicate, and is probably a derived product in part from an altered glassy base.

Epidote in the form of small and large irregular grains and

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[1] Bulletin No. 62, U. S. Geol. Survey, 1890, p. 56 et seq.

[2] Monograph No. XXXVI, U. S. Geol. Survey, 1899, p. 101.

plates is abundantly present, closely associated with chlorite and ambiphole. It varies in color from deep yellow to nearly colorless grains, with high single and double refraction, and showing strong pleochroism in the colored individuals. The somewhat idiomorphic plates show the M(001) and T(100) cleavages in their usual development.

Zoisite, when identified, was closely intergrown with the epidote, forming an epidote-zoisite aggregate, the individuals of which are differentiated by their contrasted double refraction.

Iron oxide is extremely abundant in portions of some of the sections, and to some degree in all. It is not all magnetite, as indicated by the red color of much of it. It is separated from the other constituents of the powdered rock by means of the magnet. It occurs as minute grains and crystals, and is in part primary and in part secondary. It is so abundant in some sections as to entirely mask some of the other more important constituents. Its secondary nature is frequently shown in its peripheral position surrounding the iron-bearing constituent from which it was derived.

The remaining minerals occurring in the rocks present no noteworthy features.

In the thin-sections of the purple-colored slaty rocks of the Copper World, Durgy, and Yancey mines and the "Slate Vein," in the Carolina portion of the belt, and probably the fissile greenstone from the Halifax Copper mine, in Virginia, there is strong evidence for regarding the rocks as clastic volcanics. The evidence is less plain in some sections than in others, on account of the extreme alteration having destroyed nearly all trace of the rock structure. When the texture is not entirely destroyed the microscope shows a clastic composed of igneous fragments similar in all respects to the true igneous rocks of the district.[1]

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[1] Through the kindness of Professor J. Morgan Clements, of the University of Wisconsin, I have been able to examine and compare the slides of the similar volcanic rocks of the Lake Superior region, and the similarity, as remarked by Professor Clements, is strikingly close to the rocks of the Virgilina district.

Professor Clements very kindly examined the thin-sections of the Virginia-

The microscopic study entirely fails to indicate what the original characterizing bisilicate component was in these rocks —whether augite or hornblende, or both, with possible biotite and olivine. We are in doubt, therefore, as to whether the rocks were originally augite or hornblende andesites.

Chemical Analyses.

Six analyses of the Virgilina greenstones, four complete (analyses I–V, inclusive) and two partial (VI and VII), were made by the writer in the chemical laboratory of Denison University.[1] These are compared with analyses of so-called greenstones (Catoctin schist) of the Catoctin belt of northern Virginia (analysis VIII) and with those of the well known Marquette and Negaunee districts of Michigan (analyses XIII and XIV. Also analyses I and II, representing the freshest material, are compared with analyses of andesites from Colorado (analyses IX and XII) and Maine (analysis XI).

A cursory examination of the analyses is sufficient to indicate the andesitic character of the rocks, with an advanced stage of alteration shown in IV, V, VI, and VII. Furthermore, the ratio of the SiO_2 to the base-forming elements in I and II, the least altered material, suggests an intermediate rather than an acid or basic andesite. The prevailingly low SiO_2 in the remaining analyses (IV, V, VI, and VII) is explained on the basis of advanced alteration, since the rocks yielding these results were the most altered and were highly schistose in structure. Other apparent irregularities in the analyses are likewise explained on the same basis, since the greatest irregularities are indicated in the analysis of the most

North Carolina rocks and the accompanying hand specimens here described, and in a personal memorandum to the writer stated that the rocks were igneous and of an andesite character, confirming the writer's study of the material; further, that the evidence was strong for regarding some of the volcanics as clastics composed of fragments of basic or intermediate igneous rocks similar to the igneous rocks of the district. He says: "I find they [Virginia-North Carolina rocks] are very similar to the greenstones which form so important a part of the Archæan and Algonkian of the Lake Superior region."

[1] I am indebted to Professor W. Blair Clark, of Denison University, for kindly placing at my disposal the facilities for making the analyses.

altered specimens. To what extent the ore-bearing solutions have aided in the alteration it is not possible to say, but that the change has resulted in part from such action is doubtless shown in the metalliferous veins of the district.

When I, II, and III, analyses of the least altered rock, are compared with analyses of recognized andesites occurring elsewhere, no marked differences in the essential constituents are shown.

Higher SiO_2 and Al_2O_3 and lower Fe_2O_3, FeO, CaO, and MgO in the Virgilina rocks than for the similar rocks in the Catoctin belt are noted. Na_2O is approximately the same for the two rocks, with increased K_2O shown in the Catoctin andesite. The Catoctin andesite is characterized by very high iron oxide and correspondingly low SiO_2 and clearly represents the basic type of andesite, which readily accounts for the apparent variations shown in the comparison with the Virgilina rock.

Comparing the analyses of the Virginia-North Carolina rocks with those of andesites from Colorado (analysis IX, XI, and XII) and Maine (analysis X), the differences are by no means so great as shown in the Catoctin andesite, but, on the contrary, the figures are strikingly close and uniform for rocks occurring in areas so widely separated.

Analyses XIII and XIV are of typical greenstones from the Michigan area derived, as Williams states, from the igneous rock type, diabase. A comparison of these two analyses with the average of I and II given in column III indicates at a glance those differences shown in chemical composition which distinguish a diabase from an andesite.

So far, then, as chemical analyses are trustworthy, the percentage ratios of the various constituents in the Virginia-North Carolina rocks, as indicated in I and II, and their average III, are those of andesite. Passing, then, from the least to the most altered phases of the rocks, the change is observed to consist largely in the increase in the amount of chlorite, as clearly manifested in the assumption of water, hydration; and also in increased Al_2O_3, and MgO. A similar change in the

CHEMICAL

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	64.12	62.32	63.22	51.34	48.20	46.45	49.51
TiO_2	Trace.	0.06	0.03	0.38	0.24	Trace.	0.57
Al_2O_3	16.32	15.79	16.05	20.07	22.10	13.79	22.42
Fe_2O_3	6.72	3.57	5.15	7.03	7.61	7.60	10.03
FeO	1.38	4.61	2.49	4.03	3.95	6.41	2.42
MnO	0.64	0.35	0.49	0.38	0.35	Trace.	0.42
CaO	3.49	3.65	3.57	2.83	8.86	10.13	7.68
MgO	0.33	2.53	1.43	4.18	0.86	9.81	2.81
BaO	-----	------	------	------	------	------	------
SrO	------	------	------	------	------	------	------
Na_2O	6.22	4.51	5.37	1.83	4.90	Undet.	Undet.
K_2O	0.53	0.76	0.64	5.53	1.16		
Li_2O	------	------	------	------	------	------	------
H_2O	0.34	1.89	1.11	2.90	2.31	2.66	3.41
P_2O_5	Undet.	Undet.	Undet.	Undet.	Undet.	Undet.	Undet.
SO_3	------	------	------	------	------	------	------
CO_2	None.	None.	None.	None.	None.	2.27	0.90
V_2O_3	------	------	------	------	------	------	------
	100.09	100.04	99.55	100.50	100.54	------	------

I. Andesite, dark purplish gray, massive and slightly porphyritic in texture, 0.5 mile south of Virgilina, Granville county, North Carolina; Cornfield opening. Analysis by Thomas L. Watson.

II. Dark massive greenstone; Overby opening. Analysis by Thomas L. Watson.

III. Average of I and II.

IV. Bright schistose greenstone, Blue Wing mine, 3 miles south of Virgilina, Granville county, North Carolina. Analysis by Thomas L. Watson.

V. Bright schistose greenstone, Fourth of July mine, 2.5 miles south of Virgilina, Granville county, North Carolina. Analysis by Thomas L. Watson.

VI. Bright Schistose greenstone, Anaconda mine, 1.5 miles south of Virgilina, Halifax county, Virginia. Analysis by Thomas L. Watson.

VII. Partially decayed schistose greenstone from same locality as VI. Analysis by Thomas L. Watson.

VIII. Andesite, 3.5 miles east of Front Royal, Virginia. Analysis by George Steiger, Bulletin 168, U. S. Geological Survey, 1900, page 51; described by Keith, Fourteenth Annual Report, U. S. Geological Survey, page 305.

IX. Hornblende andesite, summit of southeast spur of Galena mountain, above Big 10 claim, near Silverton, Colorado. Frank R. Van Horn, Bulletin of the Geological Society of America, 1900, volume 12, page 8.

ANALYSES.

VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
51.08	61.36	61.40	61.45	61.58	43.80	44.49	50.20	61.37
2.67	Undet.	0.79	2.80	0.49	Undet.	Undet.	------	0.60
11.37	16.56	16.59	15.07	16 96	16.08	16.37	15.43	15.41
11.17	3.44	2.13	4.46	1.75	9.47	5.07	------	3.15
5.64	2.93	3.05	1.18	2.85	10.50	5.50	13.79	3.89
0.22	Undet.	0.13	None.	Trace.	------	------	------	0.47
5.20	4.56	6.17	5.37	6.28	7.81	7.94	5.47	4.42
3.96	0.85	2.73	3.02	3.67	6.54	7.50	8.62	3.48
------	------	0.02	------	0.03	------	------	------	0.08
------	------	Trace?	------	Trace.	------	------	------	Trace.
5.54	6.86	3.83	4.00	3.94	1.96	2.59	4.75	3.76
1.50	1.30	1.34	1.22	1.28	0.34	0.56	------	0.34
------	------	Trace.	0.05	Trace.	------	------	------	------
1.50	1.55	1.70	1.23	1.30	3.99	4.99	1.74	2.99
------	------	0.20	Trace.	0.22	------	------	------	0.08
------	------	------	0.29	------	------	------	------	------
0.39	Trace.	None.	------	------	0.08	5.38	------	------
------	------	0.02	------	------	------	------	------	------
100.24	99 41	100.10	100.14	100.35	100.57	100.39	100.00	100.04

X. Andesite, Edmund's Hill, Aroostook county, Maine. Analysis by W. F. Hillebrand. Herbert E. Gregory, American Journal of Science, 1899, volume viii, page 365.

XI. Pyroxene andesite, Agate creek, Yellowstone National park. Analysis by Whitfield, Bulletin 168, U. S. Geological Survey, 1900, page 108.

XII. Hornblende andesite, Mount Shasta, California. Analysis by H. N. Stokes, Bulletin 168, U. S. Geological Survey, 1900, page 176.

XIII. Dark massive greenstone, Lower Quinnesec falls, Michigan. Analysis by R. B. Riggs. G. H. Williams, Bulletin 62, U. S. Geological Survey, 1890, page 91.

XIV. Dark schistose greenstone, forming a band in XIII. Analysis by R. B. Riggs. G. H. Williams, Bulletin 62, U. S. Geological Survey, 1890, page 91.

XV. Greenstone, summit of ridge at Cliff mine. Quoted by A. C. Lane, Geological Report on Isle Royale, Michigan, Geological Survey of Michigan, 1898–1897, volume vi, page 215.

XVI. Meta-andesite, 1.5 miles northward from Jenny Lind. Analysis by W. F. Hillebrand. Bulletin 168, U. S. Geological Survey, 1900, page 203.

rocks of the greenstone area of Michigan has been emphasized by Williams. A second and no less important change in the Virginia-North Carolina rocks is the increased amount of epidote in the much-altered phases of the rocks, a fact indicated microscopically as well as in the field, and further confirmed chemically in the greatly increased amounts of CaO in the analyses of the altered over those of the fresher rocks.

Attention is finally directed to the alkalies' ratio in these rocks, in which it is observed that K_2O is reduced to practically a minimum, while the Na_2O is proportionately increased. The constant presence of TiO_2 and MnO in the analyses is a noteworthy feature.

Evidences of Eruptive Character.

Field Evidence.

The field evidence that the schistose rocks here studied are of igneous origin is not entirely lacking when the belt as a whole is considered. While the rocks are prevailingly schistose or foliated, and in places thinly fissile, areas of much altered, though massive, rocks of the same color and texture are met in a number of places, and are most satisfactorily explained as igneous in origin. This alteration is the result of dynamic metamorphism accompanied by much chemical action, consisting largely in the abundant development of chlorite and epidote. A similar change has been observed in the greenstone areas of Michigan[1] and South Mountain,[2] Pennsylvania. In most cases where the original character is entirely lost and a perfect secondary schistosity assumed it becomes necessary to resort to the microscope to determine their nature.

In the massive and least altered phases of the rock the porphyritic structure is apparent. The porphyritic constituent measures less than one millimeter in size, and is distributed through an aphanitic groundmass of uniformly green and purple colors. The porphyritic structure is more strikingly shown

[1] Williams, G. H., Bulletin No. 62, U. S. Geol. Survey, 1890, pp. 192-217.

[2] Bascom, F., Bulletin No. 136, U. S. Geol. Survey, 1896, p. 25.

in some of the thin sections under the microscope than in the hand specimens. In such cases the porphyritic mineral consists principally of a well striated plagioclase.

The prevailing fineness of grain of these rocks, which is equally characteristic of the freshest specimens as for the most altered material, and the associated tuffs or clastic volcanics suggests solidification at the surface.

The weathered outcrops afford, as a rule, only slight indication of an igneous mass, although at one point a few miles to the south of Virgilina, in Carolina, the spheroidal type of weathering was observed. Since the rocks are usually no longer massive, but instead are highly schistose in structure, the weathered surfaces for structural reasons would be expected to more closely simulate those of sedimentary masses.

The extension of the belt as traced from the rock outcrops for many miles in an approximately north-south direction, with comparatively a very narrow cross-section, is certainly suggestive. Their weight, color, texture, and not unfrequent massive structure are properties more characteristic of igneous than of sedimentary rocks.

Massive granites and granitic gneisses, and in places dikes of diabase, limit the area on the east and west sides. In several instances the diabase is found cutting the rocks of the greenstone area. Some evidence, both field and microscopic, is at hand for regarding some of the rocks at several places in the belt as altered andesite tuffs or clastics composed of fragments of the igneous rock.[1] The study has not been sufficiently extended, however, if, indeed, it were possible, to differentiate the clastic volcanics (tuffs) from the direct igneous masses of the area.

Microscopical Evidence.

The evidence of the igneous origin of these rocks is not entirely that of field relations, but is derived largely from microscopic structure, mineral and chemical composition. In

[1] Weed, op. cit.

many instances the thin-sections show both stout and acicular forms of striated feldspar partially or wholly preserved, embedded in a fine-grained groundmass composed principally of green chlorite and hornblende, epidote, altered feldspar and iron oxide. This arrangement is not confined to the massive and least altered forms of the rocks, but is indicated to some degree in the partial skeleton outlines of some of the original minerals in several slides of the perfectly schistose rocks. In many cases chemical and structural metamorphism have progressed so far that all trace of the original structure, as well as that of every original mineral, has been destroyed.

The occurrence of lath-shaped polysynthetically twinned crystals of plagioclase which appears to have formed an essential constituent of the rocks is characteristic of rocks of igneous origin. Furthermore, the microphitic and poikilitic structures of the feldspars of some of the rocks in thin-section under the microscope are common only to igneous masses. The structures bear certain striking resemblances to similar rocks of igneous origin described by Williams[1] and Clements[2] from the Lake Superior region. Professor Williams[3] reproduces a photomicrograph of a thin-section of one of the rocks showing this structure from the Negaunee district, which has its analogue in several sections of the Virgilina rocks.

The minerals composing the rocks, which are chiefly secondary, are those which would result from chemical and structural metamorphism of an original igneous rock of basic or intermediate composition.

While, as already stated, in most instances all trace of the original minerals in the rocks is lost or destroyed, in some sections enough remains to tell with some degree of certainty what their original essential minerals were.

The analyses of these rocks given in the table on page 112

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[1] Williams, G. H., Bulletin No. 62, U. S. Geol. Survey, 1890.

[2] Clements, J. Morgan, Jour. of Geology, 1895, Vol. III, pp. 801-822; Monograph, No. XXXVI, U. S. Geol. Survey, pp. 98-103.

[3] Williams, G. H., op. cit., p. 226, plate X, figure 2.

confirm their igneous character. When compared with similar analyses of well known igneous rocks of a certain type from widely separated localities, fairly close agreement is shown in the essential chemical features. Knowing, therefore, the greatly altered condition of the bulk of the rocks in the area, such differences as are brought out in the table of analyses are readily explained on the basis of chemical and physical metamorphism.

Chemical Evidence.

The chemical analyses of these rocks have been previously discussed in this paper—pages 112–113. The close conformity in composition of the rocks (the least altered ones), as there indicated, with that of andesites from well known but widely separated localities is certainly indicative of igneous origin. Their uniform composition is in contrast with that of a series of clastic rocks, where, as shown by Rosenbusch,[1] the chemical proportions are largely accidental. The microscopical study fully confirms the chemical evidence favoring the igneous origin of these rocks.

Comparison with other Areas.

Scattered areas of ancient volcanic rocks have been recognized at various localities along the Atlantic coast by geologists, extending from New Brunswick through Maine, New Hampshire, Massachusetts, Pennsylvania, and Maryland into northern Virginia, the Carolinas, Georgia[2] and Alabama. Some of the so-called sedimentary areas of the northern Atlantic coast of the earlier geologists are now regarded as altered volcanic rocks.[3]

Areas of such volcanics have been described from eastern

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[1] Zur Auffassung der Chemischen Natur des Grundgebirges, Tschermak's Min. u. Petrog. Mitth. 1891, Vol. XII, pp. 49–61.

[2] G. H. Williams discusses this subject in the 15th Ann. Report, U. S. Geol. Survey, 1895, pp. 663–664.

[3] For a statement of the distribution of the volcanic rocks on the Atlantic coast, see Williams, Jour. Geology, 1894, II, 1–31.

Canada,[1] by Bailey, Matthew, Ellis, and Bell. In New England[2] Wadsworth, Diller, Shaler, Bayley, G. O. Smith, H. S. Williams, and Gregory have described similar areas in Massachusetts and Maine. Other similar areas are well known in Pennsylvania, Maryland, and Virginia through the investigations of G. H. Williams,[3] Keith,[4] and Bascom.[5] In the Lake Superior region[6] they have been long known through the contributions principally of Irving, Van Hise, the Winchells, Clements, Bayley, Wadsworth, Williams, and Grant.

Through the studies of Clements and Brooks areas of greenstone schists, similar to those of the Lake Superior region, and derived from an original basic igneous rock of pre-Cambrian age, have been identified in the crystalline area of Alabama.[7]

The rock types indicated in these areas vary from acid to basic volcanics in composition, according to locality, and are represented principally by such rocks as rhyolite, andesite, diabase, diorite, gabbro, and their associated tuff deposits.

From the descriptions, the rocks of the Virgilina district are closely similar in many essential features to the corresponding altered phases of the Catoctin and South Mountain areas in Virginia, Maryland, and Pennsylvania, and certain ones of the famous greenstones from the Lake Superior region. When the altered rocks, greenstones, of the various areas are traced by

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[1] Ann. Report Canadian Geol. Survey, 1877-'8 D D, 1879-80 D, 1889-'90 F, 1891.

[2] Mus. Comp. Zool. Bull., Vol. V, p. 282; ibid., Vol. VII, pp. 166-187, 1881; A. J. S., 1886, Vol. XXXII, p. 40; 8th Ann. Rept. U. S. G. S., pt. 2, p. 1043; A. J. S., 1899, Vol. VIII, p. 359; Bull. No. 165, U. S. G. S., 1900, 212 pp.

[3] A. J. S., 1892, XLIV, 482-496; Jour. Geology, 1894, II, 1-31.

[4] 14th Ann. Rept. U. S. G. S, 1894, pp. 285-395; Am. Geol., 1892, X, 365; Bull. G. S. A., II, 156, 163.

[5] Bull. No. 136, U. S. G. S., 124 pp.

[6] The literature is scattered through annual reports, monographs, and bulletins of the U. S. Geological Survey and the state reports of the surveys of Minnesota, Wisconsin, and Michigan.

[7] Geol. Survey of Alabama, Bulletin No. 5, 1896, pp. 84-96, 120-197.

means of chemical and microscopical study to the original rock type, the differences become more apparent. This difference is that which distinguishes in the original rock an andesite from a diabase, diorite, gabbro, et cetera; but, as already stated, the altered rock derived from these several types is closely similar.

Sufficient study of the ancient vocanic rocks occurring to the southwest of the Virgilina area, in North Carolina, is lacking on which to base specific comparisons. That they are altered volcanic rocks of great age, comprising both acid and basic types, is established, but the exact mineral and chemical composition, denoting the original types from which they are derived, is yet to be investigated. Megascopic descriptions and the field relations of many of the basic types indicate their striking similarity to those of the Virgilina district.

As developed from the chemical and microscopic study of the rocks of the Virgilina district, the present much altered rock, greenstone, clearly indicates its derivation from an original andesite of an intermediate basic type as contrasted with the similar Catoctin schist or greenstone, which from Keith's[1] description, is derived from a more basic andesite, diabase, or basalt.

According to Keith, the rocks of the Catoctin area are igneous in origin and represent probably two different flows—the upper, basaltic, and the lower, dioritic. In general the rocks are much altered through dynamic metamorphism and secular decay and now largely form greenish epidotic and chloritic schists, designated by Keith as the Catoctin schist. The fine-grained varieties are composed of quartz, plagioclase, epidote, magnetite, and chlorite. In the coarse-grained types the original nature of the rock is well indicated. The ophitic arragement of the coarse feldspars is definitely marked. The additional minerals in the coarse rocks are calcite, ilmenite, skeleton olivine, biotite, hematite, and, in a few instances, hornblende. The alteration products, chlorite and epidote, are abundant and characteristic. An analysis of the fresh rock by

[1] 14th Ann. Rept. U. S. G. S., 1894, p. 304 et seq.

George Steiger is shown in column VIII of the table of analyses, on pages 112–113.

The South Mountain area is shown by Williams[1] and Bascom[2] to consist of the acid volcanic rhyolite and the basic types, diabase and basalt, the latter yielding on alteration the greenstones of the region. Bascom[3] further describes the basic types of this region as holocrystalline, effusive, plagioclase-augite rocks, with or without olivine, the essential characteristics of the diabase group.

After establishing the igneous origin of the greenstones of the Menominee and Marquette districts of Michigan, Williams[4] shows the different rock types to have been olivine-gabbro, gabbro, diabase, diabase-porphyry, glassy diabase and melaphyre, and tuffs, with the two districts limited on their north and south sides by an acid series consisting of granite, granite-porphyry, and quartz-porphyry.

The original mineral constituents of these rocks are described by Williams[5] as labradorite, quartz, biotite, hornblende, diallage, augite, olivine, zircon, apatite, sphene, ilmenite, and magnetite. The secondary minerals produced by metamorphism and weathering are albite, saussurite, zoisite, quartz, hornblende, epidote, chlorite, biotite, talc, serpentine, carbonates, iron oxides and pyrite.[6]

Van Hise and Clements regard the greenstone schists of the Crystal Falls iron-bearing district as altered diabase, diabase-porphyry, and gabbro.[7] Clements[8] has shown the derivation of the greenstones of the Hemlock formation to be from original basaltic and andesitic rocks.

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[1] Op. cit.

[2] Op. cit.

[3] Ibid., p. 69.

[4] Bull. U. S. Geol. Survey, No. 62, pp. 197–199.

[5] Ibid., pp. 199, 200.

[6] Ibid., pp. 213, 214.

[7] Mono. U. S. Geol. Survey, vol. xxxvi, pp. 484-486; ibid., vol. xxviii, pp. 203-208.

[8] Ibid., vol. xxxvi, pp. 95-148.

The evidence here adduced from the descriptions of the rocks of the several areas indicates the striking fact that the present altered rock, greenstone, is remarkably similar for the several districts, but when, through chemical and microscopic means, they are traced to the original rock, distinct differentiation, such as distinguishes the various basic igneous types from each other, is shown. Moreover, not only is this striking similarity indicated in the altered rock in each instance, but the processes involved in producing the alteration have been uniformly alike. The alteration has been one of structural and chemical metamorphism, resulting in the formation of abundant chlorite and epidote and smaller amounts of other secondary minerals and the accompanying secondary schistose structure.

ORE DEPOSITS OF THE DISTRICT.[1]

The deposits of the immediate district are copper, with those of workable iron ore reported from other portions of the same counties. Copper prospecting in the district dates back forty or fifty years. The Gillis copper mine was opened in 1856,[2] exposing a large body of copper glance. Systematic work is of recent date, however.

The ore occurs mostly in quartzose veins, and to a limited extent as finely divided particles disseminated through the rocks in places. The workable ore is confined entirely to the veins. The vein stone consists principally of quartz with considerable calcite and epidote mixed locally. The altered country rock, greenstone, is intimately mixed with the quartz and calcite as thin lenses and stringers, which impart, in places, a banded structure to the vein. The included portions of the altered rock vary from mere films and dark streaks in the quartz to a preponderance of the schist with quartz infiltrated between the layers. The quartz is further frequently encased by layers of the schist wrapped around it.

[1] For a detailed description of the individual mines and the general features of the belt as a whole, see W. H. Weed, Trans. Amer. Inst. Min. Engrs., 1901, vol. xxx, pp. 449-504. An earlier account is given by Geo. B. Hanna in Ores of North Carolina, 1888, pp. 214-220.

[2] Emmons, E., Geol. Survey of North Carolina, 1856, p. 344.

The workable ore comprises glance and bornite mixed with the green carbonate, malachite—an alteration product from the original sulphides. A considerable sprinkling of the red oxide and native copper are seen in places. Genth and Kerr[1] mention the following copper minerals occurring in Person and Granville counties: chalcopyrite, chalcocite, malachite, chrysocolla, cuprite, and native copper. Chalcopyrite and pyrite are almost entirely absent from these veins. They were observed in largest amount at several shafts being opened on the High Hill property in Virginia at the time of the writer's visit.

So far as examined, the ores are free from arsenic and antimony, but are reported to carry, at times, very appreciable traces of both gold and silver, particularly the latter. The following assays of the gray ore from the Yancy mine in Person county, North Carolina, are given by Hanna,[2] and serve to illustrate the values of the mineral material.

Gold, per ton,	1-10 ounce,	1-10 ounce,	1-10 ounce.
Silver, per ton,	6 7-10 ounces,	5 1-10 ounces,	1-2 ounce.
Copper, per cent,	48.17	26.16	31.14.

In the Holloway shaft, 3.5 miles south of Virgilina, the vein has been opened to a depth of more than 500 feet, and the action of the percolating carbonated waters is shown to this depth in the occasional presence of the green carbonate, malachite, in association with the unaltered ores.

The particular interest in the ore deposits of this district is the somewhat analogous occurrence and association in many respects of the copper minerals, including native or metallic copper, in the greenstones (originally igneous in origin) to certain closely allied areas of altered igneous rocks of the Lake Superior region, and the Catoctin and South mountain areas of Virginia-Maryland-Pennsylvania, and to other smaller and less important areas in Virginia and North Carolina. Furthermore, the association of the copper with epidote is not only true of the Virgilina belt, but is described by various geologists[3] as true

[1] The Minerals and Mineral Localities of North Carolina, Raleigh, 1885, 128 pages; also Bulletin No. 74, U. S. Geol. Survey, 1891, pp. 98, 109.

[2] Op. cit., p. 220.

[3] Op. cit.

to some degree for the other areas of the Atlantic Coast and Lake Superior regions. No indications of amygdaloidal structure so common in the rocks with which the copper is intimately associated in many of the other areas is found in the Virgilina district.

In describing the general distribution of the Catoctin type of copper deposits, Weed says:

"It is evident that the association of epidote (and, to a lesser degree, of chlorite) and the native copper is a constant one, for which reason it is believed that the processes incident to the formation of the one led to the formation of the other. Such ores occur near Virgilina, Virginia, near Charlotte, North Carolina, and in many scattered localities through the South." [1]

The Ducktown copper deposits in southeastern Tennessee have been shown by Weed[2] to represent a different type from the Virgilina deposits. Both Kemp[3] and Weed[4] agree that the Ducktown ores are replacement deposits of an original calcareous sedimentary. A further difference consists in the Tennessee deposits being composed chiefly of chalcopyrite and pyrrhotite, which minerals are essentially absent from the Virgilina district.

WEATHERING.

The superficial weathered product consists of a scanty covering of light gray to brown soil. At comparatively shallow depths beneath the surface the rock manifests no tendency toward disaggregation, nor to crumble and change color when exposed at the surface, but on the contrary remains hard and fresh appearing.

The greatly altered nature of these rocks has already been emphasized. The resulting minerals from such change, epidote and chlorite, are present in large amounts in these rocks, replacing in whole or in part the original essential minerals from

[1] Trans. Amer. Inst. Min. Engrs., 1891, vol. xxx, p. 503.

[2] Ibid., pp. 449-504.

[3] Ibid., Richmond Meeting, February, 1801, pp. 18-20 (author's edition).

[4] Ibid., 1891, vol. xxx, pp 480-494.

which the above two have been derived. Epidote is usually regarded as a dynamo-metamorphic mineral, while chlorite is usually given as a product of weathering. The origin of chlorite, however, is sometimes closely associated with dynamic agencies. It is not possible, therefore, to separate the products of the processes which have produced the degree of alteration manifested in the rocks of this area. Without stating more detail, vastly the majority of change in the rocks of this area is due to dynamic action.

A suite of specimens representing the fresh and decayed rock were collected at the Anaconda mine in Virginia, a short distance north of Virgilina, for illustrating the chemical changes incidental to weathering. Here the decayed product is several feet deep, the brown color of the decayed rock passing gradually into the moderately fresh and firm green rock underneath. In columns VI and VII of the table of analyses are given chemical analyses of the fresh rock and its corresponding decayed product. The decayed rock was of a pronounced yellowish brown color, readily crumbling under slight pressure of the hand. It effervesced very feebly in dilute acid, indicating hardly more than appreciable traces of carbonates. When further digested for some time in very dilute warm HCl, the brown coloring matter was removed and the residue consisted of the usual green mineral products composing the fresh rock. The percentage of residue composed of the green colored minerals was very large.

As indicated in the analyses of the fresh and decayed rock of the table, the change has been one of hydration—the assumption of water, accompanied by the preoxidation of the iron and the partial removal of the more soluble constituents, lime, magnesia, and alkalies.

Age Relations.

Excepting the northernmost extension of the Jura-Trias to the south and southeast in the vicinity of Oxford, Granville county, North Carolina, no known clastics of definite age are found close to the area. Dikes of Mesozoic diabase are re-

ported to be rather numerous in parts of Granville county, and in several instances are observed cutting the rocks of this area. To the east, south, and west massive granites and granitic gneisses of approximately the same mineral composition are of frequent occurrence. Sufficient work has not yet been done, however, to definitely determine the exact origin of the gneisses, but in many cases their close mineralogical resemblance to the granites is suggestive of igneous origin. Indeed, a chemical analysis quoted by Kerr[1] of a similar granitic gneiss taken from the Raleigh quarries would strongly indicate, in connection with the mineral components, an original massive granite subsequently rendered schistose by pressure.

The occurrence of similar ancient volcanic rocks in the adjoining counties to the southeast of the Virgilina area, described by Williams[2] and others[3] as closely resembling those of the South Mountain area, are grouped as pre-Cambrian in age, and can be most likely correlated with the rocks of the Virgilina district.

The rocks of this district are shown to be quite similar in many respects to the volcanics farther north in Virginia and Maryland of the Catoctin belt and of South mountain, a continuation of the Catoctin belt in Pennsylvania. Keith[4] has shown the rocks of the Catoctin belt to be pre-Cambrian—Algonkian—in age. Likewise Williams[5] and Bascom[6] have shown the series of both acid and basic volcanics of South mountain in Pennsylvania to be of the same age—Algonkian.

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[1] Geology of North Carolina, Geol. Survey of N. C., 1875, vol. i, p. 122.

[2] Jour. of Geology, 1894, vol. ii, pp. 1-31.

[3] Gold Deposits of North Carolina, Geol. Survey of N. C., Bulletin no. 3, 1896, pp. 37-43; ibid., Bulletin No. 10, 1897, pp. 15, 16.

[4] Geology of the Catoctin Belt, 14th Ann. Rept., U. S. Geol. Survey, 1894, p. 319. See map, plate xxii, opposite p. 308.

[5] Volcanic Rocks of South Mountain in Pennsylvania and Maryland, Am. Jour. Sci., 1892, vol. xliv, pp. 493, 494; Jour. of Geology, 1894, vol. ii, pp. 1-31.

[6] The Ancient Volcanic Rocks of South Mountain, Pennsylvania, Bulletin No. 136, U. S. Geol. Survey, 1896, p. 30.

[6] Jour. of Geology, 1893, vol. i, pp. 813-832.

The rocks of the Virgilina district are, with few exceptions, shown to be highly schistose in structure, which is a secondary structure, and indicates that the area has been subject to long-continued dynamo-metamorphism. In view of these facts and in the absence of contradictory field evidence, the rocks are placed as pre-Cambrian in age. This is in accord with the work of Kerr and Holmes, who agree in assigning the rocks of this area to the Huronian (Algonkian),[1] and with that of Keith,[2] Williams,[3] and Bascom[4] for somewhat similar volcanics occurring to the north in Virginia, Maryland, and Pennsylvania.

It further harmonizes with the work of Williams[5] and Nitze[6] in the adjoining counties to the southwest of the Virginia district, where similar rocks are described and classified as pre-Cambrian in age. Subsequent work will probably establish the contemporaneous origin of the rocks for the several scattered areas.

Conclusions.

The principal points developed in this study may be summarized as follows:

1. The rocks of the area here described have been greatly altered through pressure and chemical metamorphim, as indicated in the prevailing secondary schistose structure and the abundant development of the secondary minerals—chlorite, epidote, and hornblende—and small amounts of others. The alteration has advanced sufficiently far in the schistose phases to destroy in most cases the original structure and minerals of the rock.

2. From structural, petrographic, and chemical evidences the rocks are shown to have been derived from an original andesite, but in their present much altered state they are, according to present usage, more properly designated meta-andesites; that these are intimately associated with the corresponding volcanic clastics. Furthermore, the popular name greenstone

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[1] Van Hise, C. R.: Correlation Papers, Bulletin No. 86, U. S. Geol. Survey.

[2] Op. cit. [3] Op. cit. [4] Op. cit. [5] Op. cit. [6] Op. cit.

applied to many areas of greatly altered massive and schistose rocks along the Atlantic Coast and Lake Superior regions, shown to have been derived from an original basic eruptive rock type, has equal application to the existing rocks of the Virgilina district.

3. The rocks are pre-Cambrian in age and represent an area of ancient volcanics similar to others described as occurring along the Atlantic Coast region from eastern Canada to Georgia and Alabama and in the Lake Superior region.

4. The rocks are cut by numerous approximately parallel quartz veins which contain workable copper deposits. The veins have been described as true fissure veins, and the ore is glance and bornite, without chalcopyrite and pyrite.

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THE BIRDS OF LICKING COUNTY, OHIO.

By I. A. FIELD

Granville, Ohio, December, 1903.

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THE BIRDS OF LICKING COUNTY, OHIO.

By I. A. Field.

Introduction.

Licking county holds a central position in the State of Ohio, being bounded on the north by Knox county, on the east by Coshocton and Muskingum, on the south by Fairfield and Perry and on the west by Franklin and Delaware counties. It lies on the 40th parallel between the 82nd and 83rd meridians. It extends 22½ miles north and south and 30 miles east and west, embracing 675 square miles. The topography of the county is quite varied, being very rough and hilly in the eastern portion while that of the west more nearly approaches a level. The western part, however, is in hummocks and hillocks, the result of glacial action. Geologically considered the eastern part of the county is a Carboniferous exposure, the middle Sub-carboniferous and the western is covered with glacial drift.

The county is drained by the Licking river which is fed by numerous small streams chief among which are the Raccoon and Licking creeks. All these streams converge towards the east.

In the southern part of the county lies the Licking reservoir which extends into Fairfield and Perry counties. This body of water covers an area of nearly 6000 acres, has many muddy beaches and is bordered for miles by a wide, swampy growth of bushes and reeds. It is a typical place for shore and aquatic birds and these may be found there in great numbers at the proper season. Washington township contains a small lake known as Hass lake which covers an area of about twenty-five acres. This is surrounded by a broad margin of swamp land which supports a very dense growth of vegetation. Besides these bodies of water, numerous small ponds are distributed here and there throughout the county. These in the spring are frequented by many different species of water-birds.

Considerable timber is distributed over the county. Most

of the hills in the eastern portion are capped by woodland and in the southern portion quite large woods extend over the low level areas.

With such a varied topography Licking county is able to attract a very rich avifauna. In the spring the rèservoir abounds in water-fowl and shore birds, the woodlands are thronged with Warblers, Kinglets and Vireos and the fields are alive with Sparrows, Larks and Doves. In the past three years nearly all of the following 203 species of birds have been recorded, representing fourteen orders and forty-four families. Of these 27 are permanent residents, 79 are summer residents, 9 are winter residents, 80 are transient visitants and 8 are accidental visitants.

It seems clear that the Robin, Bluebird and Redheaded Woodpecker are gradually becoming adapted to endure the winters of this region. When favored by a good supply of beech nuts, large numbers of Redheaded Woodpeckers may be found, on the coldest winter days, in the Spring Valley Glen. Bluebirds are fairly common in this same locality during the winter and Robins have been recorded on the college campus in January and February. It is quite evident that where there is an abundance of food for these birds the cold of winter has but little influence in driving them south.

Quite a large number of birds recorded in the county are very local in their distribution. Most of the aquatic birds are local to the Licking reservoir. The Traills Flycatcher is found only at the Licking reservoir and Hass lake during the breeding season. The Dickcissel, though pretty generally distributed through the county, is found most abundantly in Granville, Newark and Newton townships. The increase in the number of these birds in the past three years has been something phenomenal. In the spring and summer of 1901 I recorded one Dickcissel. In the spring and summer of 1902 I found them fairly common and this year, 1903, they are really abundant. Going from Granville to Newark by wheel I have counted as many as thirty along the roadside. They were perched on the telephone wires, in trees, on the fence or some waving weed from which they ceaselessly poured forth their monotonous

unmusical song. The Scarlet Tanager is another bird which is increasing in numbers and in its range. Formerly it was necessary to visit Cat run in order to see this brilliantly colored bird, but for the last two summers a pair have nested on the Denison campus in the woods back of the College dormitory. This spring several pairs of Scarlet Tanagers were found nesting in the woods located along the border line of Granville and McKean townships. The Tree Swallow has been recorded only at the Licking reservoir. In the spring of 1902 I was surprised to find the Prothonotary Warbler breeding at the Licking reservoir in considerable numbers. In the same year a single pair was recorded at Cat run.

In the list that follows an attempt has been made to give the relative abundance, distribution and the seasonal appearance of each species of bird found in Licking county. The classification, nomenclature and numeration used are those of the *A. O. U. Check-list of North American Birds* and Supplements succeeding.

In the preparation of this list I have received much kindly encouragement and advice from my friend and teacher Dr. C. Judson Herrick. Mr. Lynds Jones of Oberlin has given me important help by suggestions and a critical reading of the entire manuscript. To both of these men I wish here to express my gratitude and appreciation.

ORDER PYGOPODES. Diving Birds.

(Families Podicipidae, Urinatoridae.)

Family Podicipidae. Grebes.

3. Colymbus auritus *Linn.* Horned Grebe. Rather uncommon spring and fall migrant. Confined to the Licking reservoir.

6. Podilymbus podiceps (*Linn.*). Pied-billed Grebe. Common spring and fall migrant. It is probable that a few remain as summer residents, breeding at the Licking reservoir.

Family Urinatoridae. Loons.

7. Gavia imber (*Gunn*). Loon. Common spring and fall migrant. Found principally at the Licking reservoir where in the spring it is often found in companies of from four to ten.

ORDER LONGIPENNES. Gulls and Terns.

Family Laridae. Gulls and Terns.

51a. Larus argentatus *Brün.* Herring Gull. Tolerably common spring and fall migrant. Confined mostly to the Licking reservoir.

60. Larus philadelphia (*Ord.*). Bonaparte's Gull. Tolerably common spring and fall migrant. Usually found as single birds or in pairs at the Licking reservoir.

64. Sterna caspia *Pallas.* Caspian Tern. Rare. One record of a single individual at the Licking reservoir, May 31, 1902.

70. Sterna hirundo *Linn.* Common Tern. Common spring and fall migrant. Large numbers are sometimes found at the Licking reservoir.

77. Hydrochelidon nigra surinamensis (*Gmel.*). Black Tern. Tolerably common spring and fall migrant. Found principally at the Licking reservoir.

ORDER STEGANOPODES. Totipalmate swimmers.
(Families Phalacrocoracidae, Pelecanidae.)

Family Phalacrocoracidae. Cormorants.

120. Phalacrocorax dilopus (*Sw. and Rich.*). Double-crested Cormorant. Rare. Occasionally one is killed on the Licking reservoir.

Family Pelecanidae. Pelicans.

125. Pelecanus erythrorhynchus *Gmel.* American White Pelican. Rare. One record of a single individual killed by Mr. Stephen Holtsberry at the Licking reservoir, May 15, 1902 It had been on the reservoir for several days.

ORDER ANSERES. Lamellirostral swimmers.

Family Anatidae. Ducks, Geese, Swans.

129. Merganser americanus (*Cass.*). American Merganser; Shelldrake. Tolerably common spring and fall migrant.

130. Merganser serrator (*Linn.*). Red-breasted Merganser. Tolerably common spring and fall migrant.

131. Lophodytes cucullatus (*Linn.*). Hooded Merganser. Tolerably common spring and fall migrant.

132. Anas boschas *Linn.* Mallard. Common spring and fall migrant.

133. Anas obscura (*Gmel.*). Black Duck, Dusky Duck. Common spring and fall migrant. It is probable that these birds recorded as **obscura** are not typical of that species but belong to the newly elaborated species **A. o. rubripes,** the Red-legged Black Duck.

135. Chaulelasmus streperus (*Linn.*). GADWALL. Uncommon spring and fall migrant. Mr. Lynds Jones reports that this bird has been taken on the Licking reservoir.

136. Mareca penelope (*Linn.*). EUROPEAN WIDGEON. Accidental visitant. One record of a single individual which was killed on the Licking reservoir by Mr. Peter Hayden of Columbus, O. This is the first known record of the bird in Ohio. The bird is now mounted and in the Denison Museum.

137. Mareca americana *Gmel.* AMERICAN WIDGEON. Common spring and fall migrant. Very large flocks are sometimes seen in the spring at the Licking reservoir.

139. Nettion carolinensis *Gmel.* GREEN-WINGED TEAL. Tolerably common spring and fall migrant. Found principally at the Licking reservoir.

140. Qurquedula discors *Linn.* BLUE-WINGED TEAL. Common spring and fall migrant. Visits nearly all the small ponds and lakes of the county.

141. Querquedula cyanoptera (*Vieill.*). CINNAMON TEAL. Accidental visitant. One bird was killed on the Licking reservoir by Mr. William Harlow.

142. Spatula clypeata (*Linn.*). SHOVELLER. Common spring and fall migrant. Often found in ditches and on ponds in open fields.

143. Dafila acuta (*Linn.*). PINTAIL; SPRIGTAIL. Common spring and fall migrant. Found principally at the Licking reservoir.

144. Aix sponsa (*Linn.*). WOOD DUCK. Rather uncommon spring and fall migrant. Each year's record shows a decrease in their numbers.

146. Aythya americana (*Eyt.*). REDHEAD. Tolerably common spring and fall migrant. Found only at the Licking reservoir.

147. Aythya vallisneria (*Wils.*). CANVAS-BACK. Rather uncommon spring and fall migrant. Found only at the Licking reservoir.

148. Aythya marila (*Linn.*). AMERICAN SCAUP DUCK. Uncommon spring and fall migrant. Recorded only at the Licking reservoir.

149. Aythya affinis (*Eyt.*). LESSER SCAUP DUCK. Abundant spring and fall migrant. Flocks numbering two hundred birds or more may be seen at the Licking reservoir.

150. Aytha collaris (*Donov.*). RING-NECKED DUCK. Common spring and fall migrant. Found at the Licking reservoir.

151. Clangula americana (*Bonap.*). AMERICAN GOLDEN-EYE. Tolerably common spring and fall migrant. Found on our larger streams as well as at the Licking reservoir.

152. Clangula islandica (*Gmel.*). BARROWS' GOLDEN-EYE. Rather uncommon spring and fall migrant. Found at the Licking reservoir.

153. Charitonetta albeola (*Linn.*). BUFFLEHEAD; BUTTER-BALL. Common spring and fall migrant.

154. Harelda hyemalis (*Linn.*). Old Squaw. Rather uncommon spring and fall migrant. One was killed on Raccoon creek, Feb. 12, 1902, and is now mounted and in the possession of W. H. Ports, Granville, O. They occur principally at the Licking reservoir.

165. Oidemia delegandi *Bonap.* White-winged Scoter. Rare. Mr. Lynds Jones of Oberlin reported one at the Licking reservoir, Apr. 3, 1903. He expressed some doubt as to its actual identity, however, on account of being at a considerable distance from the bird.

167. Erasmatura jamaicensis (*Gmel.*). Ruddy Duck. Rather uncommon spring and fall migrant Recorded only at the Licking reservoir.

172. Branta canadensis (*Linn.*). Canada Goose. Rather uncommon spring and fall migrant. Some years they are more common than in others. On Oct. 19, 1902, I counted more than a hundred on the Licking reservoir.

172a. Branta canadensis hutchinsii (*Sw. and Rich.*). Hutchin's Goose. Mr. William Harlow has a live specimen that he captured on the Licking reservoir.

173. Branta bernicla (*Linn.*). Brant. Rare. One doubtful record of one at the Licking reservoir, May 30, 1902.

181. Olor buccinator (*Rich.*). Trumpeter Swan. Uncommon spring and fall migrant. One record of three at the Licking reservoir, March 28, 1903.

ORDER HERODIONES. Herons and Bitterns.

Family Ardeidae.

190. Botaurus lentiginosus (*Montag.*). American Bittern. Tolerably common summer resident from April to November. Breeds at Hass lake and the Licking reservoir. Found about almost any of the marshy ponds in the county during the spring and fall migration season.

191. Ardetta exilis (*Gmel.*). Least Bittern. Very common summer resident from May to October. Breeds at Licking reservoir.

194. Ardea herodias *Linn.* Great Blue Heron. Tolerably common summer resident. Breeds at Licking reservoir.

197. Ardea candidissima *Gmel.* Snowy Heron. Very rare. One record of Aug. 20, 1901 at the Licking reservoir. Dr. J. M. Wheaton in his Report on The Birds of Ohio. p. 502, reports having seen five of these birds at Granville in the summer of 1859. "These were apparently all young."

201. Ardea virescens *Linn.* Green Heron. Common summer resident from April to October. Generally distributed throughout the county. Nests in trees along the larger streams and in orchards.

ORDER PALUDICOLAE.

Family Rallidae. Rails, Coots, Gallinules.

208. Rallus elegans *Aud.* King Rail. Rather uncommon summer resident from May to October. Breeds at the Licking reservoir.

212. Rallus virginianus *Linn.* Virginia Rail. Common summer resident from May to October. Breeds at Hass lake and the Licking reservoir.

214. Porzana carolina (*Linn.*). Sora; Carolina Rail. Common summer resident from April to November. Breeds at Hass lake and the Licking reservoir.

219. Gallinula galeata (*Licht.*). Florida Gallinule. Common summer resident from May to October. Breeds at the Licking reservoir.

221. Fulica americana *Gmel.* American Coot. Abundant spring and fall migrant. Often I have seen several hundred together on the Licking reservoir. It is probable that a few remain as summer residents breeding at the reservoir.

ORDER LIMICOLAE. Shore Birds.

(Families, Scolopacidae, Charadriidae.)

Family Scolopacidae. Snipes and Sandpipers.

228. Philohela minor. (*Gmel.*). American Woodcock. Rather uncommon summer resident from April to October.

230. Gallinago delicata (*Ord.*). Wilson's Snipe. Tolerably common spring and fall migrant in April and May, September and October.

239. Tringa maculata *Vieill.* Pectoral Sandpiper. Common spring and fall migrant. Frequents wet fields and meadows.

242. Tringa minutilla *Vieill.* Least Sandpiper. Uncommon spring and fall migrant. Frequents the muddy shores on the north end of the Licking reservoir.

246. Ereunetes pusillus (*Linn.*). Semipalmated Sandpiper. Tolerably common spring and fall migrant. Found at the Licking reservoir.

248. Calidris arenaria (*Linn.*). Sanderling. Uncommon migrant. It may usually be found in small numbers at the Licking reservoir during September and October.

254. Totanus melanoleucus (*Gmel.*). Greater Yellow-legs. Tolerably common spring and fall migrant.

255. Totanus flavipes (*Gmel.*). Yellow-legs. Common spring and fall migrant.

256. Helodromas solitarius (*Wils.*). Solitary Sandpiper. Tolerably common migrant and after the middle of July a summer resident. Does not breed. Frequents small ponds, the larger ditches and the muddy shores of the Licking reservoir.

261. Bartramia longicauda (*Bechst.*). Bartramian Sandpiper. Tolerably common summer resident from April to October. Breeds.

263. Actitis macularia (*Linn.*). Spotted Sandpiper. Common summer resident from April to October. Breeds.

264. Numenius longirostris *Wils.* Long-billed Curlew. Rare migrant. One record of seven at the Licking reservoir May 31, 1902.

Family Charadriidae. Plovers.

273. Aegialitis vocifera (*Linn.*) Killdeer. Common summer resident from March to October. Breeds.

ORDER GALLINAE. Gallinaceous Birds.

Family Tetraonidae. Grouse, Bob-whites.

289. Colinus virginianus (*Linn.*). Bob-white, Quail. Common permanent resident. Breeds. Well distributed throughout whole county.

300. Bonasa umbellus (*Linn.*). Ruffed Grouse. Uncommon permanent resident. Confined almost entirely to the south-eastern part of the county.

ORDER COLUMBAE. Pigeons and Doves.

Family Columbidae.

316. Zenaidura macroura (*Linn.*). Mourning Dove. Very common summer resident from latter part of January to November. Breeds.

ORDER RAPTORES. Birds of Prey.

(Families Cathartidae, Falconidae, Strigidae, Bubonidae.)

Family Cathartidae. American Vultures.

325. Cathartes aura (*Linn.*). Turkey Vulture. Common summer resident from February to November. Breeds.

Family Falconidae. Falcons, Hawks, Eagles.

331. Circus hudsonius (*Linn.*). Marsh Hawk; Harrier. Tolerably common summer resident from April to October. Probably breeds in vicinity of the Licking reservoir.

332. Accipter velox (*Wils.*). Sharp-shinned Hawk. Tolerably common permanent resident. Breeds.

333. Accipter cooperi (*Bonap.*). Cooper's Hawk. Tolerably common permanent resident. Breeds.

337. Buteo borealis (*Gmel.*). Red-tailed Hawk. Common permanent resident. Breeds.

339. Buteo lineatus (*Gmel.*). RED-SHOULDERED HAWK. Common permanent resident. Breeds.

343. Buteo platypterus (*Vieill.*). BROAD-WINGED HAWK. This bird is reported as rare and not breeding by Mr. Raymond Osburn of Vanatta.

352. Haliæetus leucocephalus (*Linn.*). BALD EAGLE. Rather uncommon and irregular in its appearances. Probably breeds in the vicinity of the Licking reservoir. A specimen in the Denison museum was taken Dec. 11, 1900.

357. Falco columbarius *Linn.* PIGEON HAWK. Uncommon spring and fall migrant.

360. Falco sparverius *Linn.* SPARROW HAWK. Common summer resident from April to November. Breeds.

364. Pandion haliaetus carolinensis (*Gmel.*). AMERICAN OSPREY. Rather uncommon summer resident from April to October. Breeds at the Licking reservoir.

FAMILY STRIGIDAE. BARN OWLS.

365. Strix pratincola *Bonap.* AMERICAN BARN OWL. Rare. Two specimens have been brought in by farmers, within the last two years, who wished to have them mounted. Possibly a summer resident.

FAMILY BUBONIDAE. HORNED OWLS, HOOT OWLS, ETC.

366. Asio wilsonianus (*Less.*). AMERICAN LONG-EARED OWL. Uncommon permanent resident. Probably breeds near the east end of the Licking reservoir where it is most commonly found.

367. Asio accipitrinus (*Pall.*). SHORT-EARED OWL. Rather uncommon permanent resident but very common winter visitant from October to May. Probably breeds about the Licking reservoir.

368. Syrnium nebulosum (*Forst.*). BARRED OWL. Common permanent resident. Breeds.

373. Megascops asio (*Linn.*). SCREECH OWL. Common permanent resident. Breeds.

375. Bubo virginianus (*Gmel.*). GREAT HORNED OWL. Tolerably common permanent resident. Breeds.

376. Nyctea nyctea (*Linn.*). SNOWY OWL. Rare winter visitant.

ORDER COCCYGES. CUCKOOS, KINGFISHERS.

(Families Cuculidae, Alcidinidae.)

FAMILY CUCULIDAE. CUCKOOS.

387. Coccyzus americanus (*Linn.*). YELLOW-BILLED CUCKOO. Common summer resident from May to October. Breeds.

388. Coccyzus erythrophthalmus (*Wils.*). Black-billed Cuckoo. Tolerably common summer resident from May to October. Breeds.

Family Alcidinidae. Kingfishers.

390. Ceryle alcyon (*Linn.*). Belted Kingfisher. Common summer resident from March to December. Breeds.

ORDER PICI. Woodpeckers, etc.

Family Picidae. Woodpeckers.

393. Dryobates villosus (*Linn.*). Hairy Woodpecker. Tolerably common permanent resident. Breeds.

394c. Dryobates pubescens medianus (*Swains.*) Downy Woodpecker. Common permanent resident. Breeds.

402. Sphyrapicus varius (*Linn.*). Yellow-bellied Sapsucker. Common spring and fall migrant.

406. Melanerpes erythrocephalus (*Linn.*). Red-headed Woodpecker. Very common summer resident from April to October. When food is plentiful a few remain over for the winter. A good crop of beech nuts kept a large number of these birds over the winter of 1902-03. On January 18, 1902, I counted twenty-six in Spring Valley glen.

409. Melanerpes carolinus (*Linn.*). Red-Bellied Woodpecker. Tolerably common permanent resident. Breeds.

412a. Colaptes auratus luteus *Bangs.* Northern Flicker. Common summer resident from April to November. Sometimes a few, favored by plenty of food, remain over the winter.

ORDER MACROCHIRES. Nighthawks, Swifts, Hummingbirds.
(Families Caprimulgidae, Micropodidae, Trochilidae.)

Family Caprimulgidae. Nighthawks, Whip-poor-wills.

417. Antrostomus vociferus (*Wils.*). Whip-poor-will. Tolerably common summer resident from May to October. Breeds.

420. Chordeiles virginianus (*Gmel.*). Nighthawk. Common summer resident from May to October. Breeds.

Family Micropodidae. Swifts.

423. Chaetura pelagica (*Linn.*). Chimney Swift. Abundant summer resident from April to October. Breeds.

Family Trochilidae. Hummingbirds.

428. Trochilus colubris (*Linn.*). Ruby-throated Hummingbird. Common summer resident from May to October. Breeds.

ORDER PASSERES. Perching Birds.

(Families Tyrannidae, Alaudidae, Corvidae, Icteridae, Fringillidae, Tanagridae, Hirundinidae, Ampelidae, Laniidae, Vireonidae, Mniotiltidae, Motacillidae, Troglodytidae, Certhiidae, Paridae, Sylviidae and Turdidae.)

Family Tyrannidae. Flycatchers.

444. Tyrannus tyrannus (*Linn.*). Kingbird. Common summer resident from April to September. Breeds.

452. Myiarchus crinitus (*Linn.*). Crested Flycatcher. Common summer resident from May to September. Breeds.

456. Sayornis phoebe (*Lath.*). Phoebe. Common summer resident from March to November. Breeds.

461. Contopus virens (*Linn.*). Wood Pewee. Common summer resident from May to September. Breeds.

465. Empidonax virescens (*Vieill.*). Green-crested Flycatcher. Common summer resident from May to September. Breeds.

466. Empidonax traillii (*Aud.*). Traill's Flycatcher. Common summer resident from May to September. Breeds at Hass lake and the Licking reservoir.

467. Empidonax minimus *Baird.* Least Flycatcher. Uncommon spring and fall migrant.

Family Alaudidae. Larks.

474. Otocoris alpestris (*Linn.*). Horned Lark. Tolerably common winter resident from November to April.

474b. Otocoris alpestris praticola *Hensh.* Prairie Horned Lark. Tolerably common summer resident from April to October. Breeds.

Family Corvidae. Crows, Jays, etc.

477. Cyanocitta cristata (*Linn.*). Blue Jay. Common permanent resident. Breeds.

488. Corvus americanus *Aud.* American Crow. Common summer resident from February to December. Some years a few remain through the winter.

Family Icteridae. Blackbirds, Orioles, etc.

494. Dolichonyx oryzivorus (*Linn.*). Bobolink. Tolerably common summer resident from May to September. Breeds.

495. Molothrus ater (*Boda.*). Cowbird. Common summer resident from March to October. Breeds.

498. Agelaius phoeniceus (*Linn.*). Red-winged Blackbird. Abundant summer resident from March to November. Breeds.

501. Sturnella magna (*Linn.*). Meadowlark. Very common summer resident from March to November. Breeds. A few sometimes remain through the winter.

506. Icterus spurius (*Linn.*). Orchard Oriole. Common summer resident from May to September. Breeds.

507. Icterus galbula (*Linn.*). Baltimore Oriole. Common summer resident from April to September. Breeds.

509. Scolecophagus carolinus (*Müll.*). Rusty Blackbird. Tolerably common spring and fall migrant.

511b. Quiscalus quiscula aeneus (*Ridgw.*). Bronzed Grackle. Abundant summer resident from March to November. Breeds.

Family Fringellidae. Finches, Sparrows, etc.

517. Carpodacus purpureus (*Gmel.*). Purple Finch. Tolerably common spring and fall migrant.

521. Loxia curvirostra minor (*Brehm.*). American Crossbill. Rare and irregular winter visitant.

529. Astragalinus tristis (*Linn.*). Goldfinch. Common permanent resident. Breeds.

533. Spinus pinus (*Wils.*). Pine Siskin. Tolerably common irregular visitant. On April 7, 1901, eight of these birds in full song were recorded on the college campus.

534. Passerina nivalis (*Linn.*). Snowflake. Mr. Raymond Osburn of Vanatta reports the snowflake as a rare visitant and not breeding.

536. Calcarius lapponicus (*Linn.*). Lapland Longspur. Tolerably common winter visitant from December to March.

540. Poœcetes gramineus (*Gmel.*). Vesper Sparrow. Very common summer resident from March to November. Breeds.

543a. Ammodramus sandwichensis savanna (*Wils.*). Savanna Sparrow. Tolerably common spring and fall migrant.

546. Ammodramus sandwichensis passerinus (*Wils.*). Grasshopper Sparrow. Very common summer resident from April to August. Breeds.

547. Ammodramus henslowii (*Aud.*). Henslow's Sparrow. Rare. One record of one, April 21, 1903.

552. Chondestes grammacus (*Say.*). Lark Sparrow. Rather uncommon summer resident from April to August. Breeds.

554. Zonotrichia leucophrys (*Forst.*). White-crowned Sparrow. Tolerably common spring and fall migrant.

558. Zonotrichia albicollis (*Gmel.*). WHITE-THROATED SPARROW. Common spring and fall migrant.

559. Spizella monticola (*Gmel.*). TREE SPARROW. Very common winter resident from November to April.

560. Spizella socialis (*Wils.*). CHIPPING SPARROW. Very common summer resident from April to November. Breeds.

563. Spizella pusilla (*Wils.*). FIELD SPARROW. Very common summer resident from April to November. Breeds.

567. Junco hyemalis (*Linn.*). SLATE-COLORED JUNCO. Common winter resident from October to April.

581. Melospiza melodia (*Wils.*). SONG SPARROW. Very common permanent resident. Breeds.

583. Melospiza lincolni (*Aud.*). LINCOLN'S SPARROW. Rather uncommon spring and fall migrant in May and October.

584. Melospiza georgiana (*Lath.*). SWAMP SPARROW. Rather uncommon spring and fall migrant in April, October and November. Usually found in company with M. lincolni.

585. Passerella iliaca (*Merr.*). FOX SPARROW. Rather uncommon spring and fall migrant in March and April, October and November.

587. Pipilo erythrophthalmus (*Linn.*). TOWHEE. Common summer resident from March to November. Breeds.

593. Cardinalis cardinalis (*Linn.*). CARDINAL. Common permanent resident. Breeds.

595. Zamelodia ludoviciana (*Linn.*). ROSE-BREASTED GROSBEAK. Tolerably common summer resident from May to September. Breeds.

598. Cyanospiza cyanea (*Linn.*) INDIGO BUNTING. Very common summer resident from May to October. Breeds.

604. Spiza americana (*Gmel.*). DICKCISSEL. Very common summer resident from May to September. Breeds. More abundantly distributed through the eastern half of the county.

FAMILY TANAGRIDAE. TANAGERS.

608. Piranga erythromelas *Vieill.* SCARLET TANAGER. Tolerably common summer resident from April to late in September. Breeds. Each year's record since 1900 shows an increase in the number of these birds.

610. Piranga rubra (*Linn.*). SUMMER TANAGER. Rare. Messrs. J. F. VanVoorhis and W. C. Metz report one pair breeding in a woods two miles south of Newark.

FAMILY HIRUNDINIDAE. SWALLOWS.

611. Progne subis (*Linn.*). PURPLE MARTIN. Common summer resident from April to September. Breeds.

612. Petrochelidon lunifrons (*Say.*). CLIFF SWALLOW. Tolerably common summer resident from April to September.

613. Hirundo erythrogastra *Bodd.* BARN SWALLOW. Tolerably common summer resident from April to September. Breeds.

614. Tachycineta bicolor (*Vieill.*). TREE SWALLOW. Tolerably common summer resident from April to September. Breeds in the vicinity of Licking reservoir.

616. Clivicola riparia (*Linn.*). BANK SWALLOW. Tolerably common summer resident from April to September. Breeds.

617. Stelgidopteryx serripennis (*Aud.*). ROUGH-WINGED SWALLOW. Common summer resident from April to September.

FAMILY AMPELIDAE. WAXWINGS.

619. Ampelis cedrorum (*Vieill.*). CEDAR WAXWING. Very common summer resident from April to November. Breeds.

FAMILY LANIIDAE. SHRIKES.

621. Lanius borealis *Vieill.* NORTHERN SHRIKE. Rare winter visitant.

622. Lanius ludovicianus *Linn.* LOGGERHEAD SHRIKE. Tolerably common summer resident from March to September. Breeds.

FAMILY VIREONIDAE. VIREOS.

624. Vireo olivaceous (*Linn.*). RED-EYED VIREO. Common summer resident from April to October. Breeds.

627. Vireo gilvus (*Vieill.*) WARBLING VIREO. Common summer resident from April to November. Breeds.

628. Vireo flavifrons *Vieill.* YELLOW-THROATED VIREO. Tolerably common summer resident from May to September. Breeds.

629. Vireo solitarius (*Wils*). BLUE-HEADED VIREO. Mr. Raymond Osburn of Vanatta reports this bird as rare and not breeding.

631. Vireo noveboracensis (*Gmel.*). WHITE-EYED VIREO. Uncommon spring and fall migrant. One pair remained on the Denison campus from April 6 to 16, 1903.

FAMILY MNIOTILTIDAE. WOOD WARBLERS.

636. Mniotilta varia (*Linn.*). BLACK AND WHITE WARBLER. Common spring and fall migrant and uncommon summer resident from April to September. Breeds

637. Protonotaria citrea (*Bodd.*) PROTHONOTARY WARBLER. Tolerably common summer resident from May to September. Very common and breeding at the Licking reservoir. One pair found nesting at Cat run May 24, 1902.

639. Helmitherus vermivorus (*Gmel.*). WORM-EATING WARBLER. Rare spring and fall migrant in May and August. One record of two May 7, 1902, another of two May 11, 1903.

641. Helminthophila pinus (*Linn.*). BLUE-WINGED WARBLER. Rather uncommon summer resident from May to September. Breeds.

645. Helminthophila rubricapilla (*Wils.*). NASHVILLE WARBLER. Tolerably common spring and fall migrant in May and September.

647. Helminthophila peregrina (*Wils.*). TENNESSEE WARBLER. Uncommon spring and fall migrant in May and September.

648. Compsothlypis americana usneæ *Brewst.* NORTHERN PARULA WARBLER. Uncommon spring and fall migrant in May and September.

652. Dendroica aestiva (*Gmel.*). YELLOW WARBLER. Abundant summer resident from last of April to September.

654. Dendroica caerulescens (*Gmel.*). BLACK-THROATED BLUE WARBLER. Common spring and fall migrant in May and September.

655. Dendroica coronata (*Linn.*). MYRTLE WARBLER. Very common spring and fall migrant in April and May, September and October.

657. Dendroica maculosa (*Gmel.*). MAGNOLIA WARBLER. Common spring and fall migrant in May and September.

658. Dendroica rara *Wils.* CERULEAN WARBLER. Common summer resident from the last of April to August. Breeds.

659. Dendroica pensylvanica (*Linn.*). CHESTNUT-SIDED WARBLER. Tolerably common spring and fall migrant in May and September.

660. Dendroica castanea (*Wils.*). BAY-BREASTED WARBLER. Common spring and fall migrant in May, September and October.

661. Dendroica striata (*Forst.*). BLACK-POLL WARBLER. Uncommon spring and fall migrant in May, September and October. More common in the fall.

662. Dendroica blackburniae (*Gmel.*). BLACKBURNIAN WARBLERS. Common spring and fall migrant in May and September.

667. Dendroica virens (*Gmel.*). BLACK-THROATED GREEN WARBLER. Common spring and fall migrant in May, September and October.

674. Seiurus aurocapillus (*Linn.*). OVEN-BIRD. Tolerably common summer resident from April to September. Breeds.

675. Seiurus noveboracensis (*Gmel.*). WATER-THRUSH. Uncommon spring and fall migrant during April, August and October.

676. Seiurus motacilla (*Vieill.*). LOUISIANA WATER-THRUSH. Uncommon. One specimen taken at Licking reservoir March 27, 1902.

681b. Geothlypis trichas brachidactyla (*Swainson.*) NORTHERN YELLOW-THROAT. Common summer resident from April to September. Breeds.

683. Icteria virens (*Linn.*). YELLOW-BREASTED CHAT. Common summer resident from May to August. Breeds.

686. Wilsonia canadensis (*Linn*). CANADIAN WARBLER. Tolerably common spring and fall migrant in May and September.

687. Setophaga ruticilla (*Linn.*). AMERICAN REDSTART. Common summer resident from May to September. Breeds.

FAMILY MOTACILLIDAE. PIPITS.

697. Anthus pensilvanicus (*Lath.*). AMERICAN PIPIT. Tolerably common spring and fall migrant in April and May, October and November.

FAMILY TROGLODYTIDAE. THRASHERS, WRENS, ETC.

704. Galeoscoptes carolinensis (*Linn.*). CATBIRD. Very common summer resident from April to October. Breeds.

705. Toxostoma rufum (*Linn.*). BROWN THRASHER. Tolerably common summer resident from April to September.

718. Thryothorus ludovicianus (*Lath.*). CAROLINA WREN. Common permanent resident. Breeds.

721. Troglodytes aedon *Vieill.* HOUSE WREN. Uncommon summer resident from April to October. Breeds. Three years ago it was tolerably common but since then it has been on the gradual decrease.

722. Olbiorchilus hiemalis (*Vieill.*). WINTER WREN. Common winter resident from October to April.

725. Cistothorus palustris (*Wils.*). LONG-BILLED MARSH WREN. Common summer resident from April to late in October. Breeds at Hass lake and the Licking reservoir.

FAMILY CERTHIIDAE. CREEPERS.

726. Certhia familiaris fusca (*Barton.*). BROWN CREEPER. Common spring and fall migrant and tolerably common winter resident from October to May.

FAMILY PARIDAE. NUTHATCHES AND TITS.

727. Sitta carolinensis *Lath.* WHITE-BREASTED NUTHATCH. Common permanent resident. Breeds.

728. Sitta canadensis *Linn.* RED-BREASTED NUTHATCH. Uncommon spring and fall migrant in March, April and May, October and November.

731. Parus bicolor *Linn.* TUFTED TITMOUSE. Very common permanent resident. Breeds.

735. Parus atricapillus (*Linn.*). CHICKADEE. Common permanent resident. Breeds.

736. Parus carolinensis *Aud.* CAROLINA CHICKADEE. Tolerably common permanent resident. Breeds.

FAMILY SYLVIIDAE KINGLETS AND GNATCATCHERS.

748. Regulus satrapa *Licht.* GOLDEN-CROWNED KINGLET. Abundant spring and fall migrant in March and April, October and November.

749. Regulus calendula (*Linn.*). RUBY-CROWNED KINGLET. Abundant spring and fall migrant in April, October and November.

751. Polioptila caerulea (*Linn.*). BLUE-GRAY GNATCATCHER. Tolerably common summer resident from April to September. Breeds.

FAMILY TURDIDAE. THRUSHES, BLUEBIRDS, ETC.

755. Hylocichla mustelina *Gmel.* WOOD THRUSH. Common summer resident from May to October. Breeds.

756. Hylocichla fuscescens *Steph.* WILSON'S THRUSH; VEERY. Common spring and fall migrant in May, August and September.

757. Hylocichla aliciae (*Baird.*). GRAY-CHEEKED THRUSH. Tolerably common spring and fall migrant in April and May, September and October.

758a. Hylocichla swainsonii (*Cab.*). OLIVE-BACKED THRUSH. Very common spring and fall migrant in May, September and October. In the fall this and the preceding species are often found together feeding upon wild cherries and pokeberries.

759b. Hylocichla guttata pallasii (*Cab.*). HERMIT THRUSH. Rather uncommon spring and fall migrant in April and October.

761. Merula migratoria (*Linn.*). AMERICAN ROBIN. Abundant summer resident from February to November. Breeds. Occasionally a few individuals remain through the winter.

766. Sialia sialis (*Linn.*). BLUEBIRD. Very common summer resident from February to November. Breeds. A few individuals usually remain through the winter.

INTRODUCED SPECIES.

Passer domesticus (*Linn.*). ENGLISH SPARROW. Abundant permanent resident. Breeds.

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OF

DENISON UNIVERSITY.

EDITED BY
THOMAS L. WATSON,
Permanent Secretary Denison Scientific Association.

GEOLOGICAL RELATIONS OF THE MANGANESE ORE-DEPOSITS OF GEORGIA.

By THOMAS L. WATSON

Granville, Ohio, March, 1904.

NOV

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GEOLOGICAL RELATIONS OF THE MANGANESE ORE DEPOSITS OF GEORGIA.[1]

BY THOMAS L. WATSON.

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[1] Published by permission of the State Geologist of Georgia.

I wish to make acknowledgements to the various excellent maps and publications of the U. S. Geol. Survey, by Dr. C. W. Hayes, on the Georgia area; and to the valuable volume on "Manganese," by Dr. R. A. F. Penrose, issued by the Arkansas Geol. Survey, all of which have been freely used in the preparation of this paper.

Reprinted from *Transactions of the American Institute of Mining Engineers*. (Albany Meeting, February, 1903, 47 pages.)

[2] Omitted in the original paper.

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Introduction.

A part of the field-seasons of 1900, 1901 and 1902 was devoted by the writer to a study of the manganese ore-deposits of Georgia. A report embodying the results of this study is rapidly nearing completion, and when finished it will be published as a bulletin of the Geological Survey of Georgia. I believe, however, the importance of these deposits warrants a separate and earlier publication than that made possible by the Survey, in which the more important results of the study are briefly set forth. It is principally for this reason that the present paper has been prepared.

Previous Work.—Some of the more important deposits of manganese occurring in the Paleozoic area of Georgia were studied to some extent previous to 1890 by Dr. Penrose ;[1] and again in the early nineties by former State Geologist, J. W. Spencer.[2] In a recent paper published in the *Transactions*, on the "Geological Relations of the Iron-Ores in the Cartersville District, Georgia," Dr. Hayes[3] briefly mentions the manganese-ores of the same district.

Distribution of the Manganese-Ores.—Georgia is divisible into three geologically-distinct areas which, named in order from southeast to northwest, are (*a*), the Coastal Plain ; (*b*), the Crystalline Area ; and (*c*), the Paleozoic Group. The areas are sharply marked one from the other by two strongly defined structural lines. First, the fall-line, which crosses the State in a slightly south of west direction, passing through or near the cities of Augusta, Macon and Columbus, separates the Coastal Plain sediments on the southeast from the Crystalline area. And second, the Cartersville overthrust fault separates the Crystalline area from the Paleozoic area on the northwest. The position of both the fall line and the Cartersville fault are indicated on the sketch-map (Fig. 1) by the heavy broken lines.

The manganese ores are limited in occurrence to the northern part of the State, distributed irregularly to some extent over parts of both the Paleozoic and Crystalline areas. The commercially important deposits are confined to the northwestern part of the State in the Paleozoic area. Small shipments, not amounting to more than a few tons in all, have been made of ores mined in different parts of the Crystalline area. No deposits of manganese are yet known to occur within the limits of the Coastal Plain.

Fig. 1, a sketch map of the northern half of Georgia, shows the distribution of the manganese-deposits in the State,

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[1] "Manganese : Its Uses, Ores and Deposits," *Annual Report of the Arkansas Geol. Survey*, vol. i, p. 417 *et seq.*

[2] "The Paleozoic Group," *Geol. Survey of Georgia*, 1893, pp. 190-209.

[3] *Trans.*, xxx., 403-419 (1901).

indicated by the solid black areas. The map further shows the outline of the areas covered by the Crystalline and Paleozoic rocks, and the extreme northwestern part of the Coastal Plain along the fall-line. That part of the Coastal Plain indicated on the map has its greatest width in a north-south direction along the eastern margin, extending south from Augusta.

The manganese-deposits of the two geologically different areas are best considered separately under I. The manganese-deposits of the Paleozoic area; and II. The manganese-deposits of the Crystalline area.

I. The Manganese-Deposits of the Paleozoic Area.

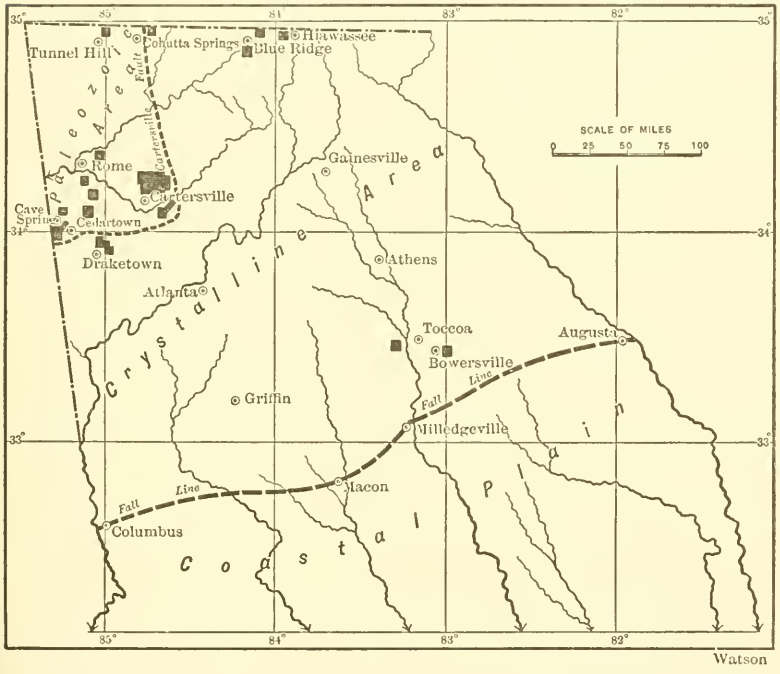
Résumé of the Geology of the Paleozoic Area.

Position.—The position of the Paleozoic area is shown on the accompanying map (Fig. 1). The area includes the ten northwest counties of the State, and is separated on the east and south from the Crystalline area by the Cartersville overthrust fault. It forms a part of the southern extension of the great Appalachian valley southwestward into Alabama.

Topography.—The region as defined above is a long, narrow belt in which the valley-type predominates, and the axis of which has a general northeast-southwest trend. When viewed in detail, it is observed to be composed of numerous subordinate valleys, separated by more or less extensive parallel ridges, whose axial directions are coincident with the general trend of the valley province. This ridge valley type of topography bears a definite relation to the rock-structure of the area. The ridges mark the lines of more resistant rock, while the valleys are etched out of the soft shales and limestones. According to the character of the rocks composing the ridges, and the position of the beds with respect to the horizon, the ridges are high or low, rather broad and flat-topped or narrow, and sharp-crested. The Knox dolomite, one of the most persistent formations in the area, and of intermediate hardness, forms a plateau of moderate elevation (between 900 and 950 ft. above mean-tide level) whose surface is gently undulating, usually not marked by any sharp ridges or peaks.

Traces of at least three rather distinct base-leveled plains appear in the region. According to Hayes[1] the highest and earliest one of these plains was probably formed during Cretaceous time, and the period of rest during which the atmospheric forces were operative is believed to have been much longer than that of the formative period of either one of the subsequent plains. The present streams were revived by the recent uplift, and they are now engaged in sinking their channels in the surface of the last base-level.

FIG. 1.



Sketch-Map of a Part of Georgia, Showing the Distribution of the Manganese-Deposits (Represented by the Black Areas).

Stratigraphy.—The rocks of the region range in age from lower Cambrian to Carboniferous, and they include slates, limestones, shales, sandstones and conglomerates. No igneous

[1] *Sixteenth Annual Report U. S. Geol. Survey*, 1895, Part III., pp. 553-554.

rocks are yet known to occur within the limits of the area. The manganese-deposits are limited to the residual decay resting on and derived from only three of the formations, namely, the Weisner quartzite, Beaver limestone and Knox dolomite. These formations are described in sufficient detail under the Cartersville and Cave Spring districts of this paper, and they need not be repeated here. (See Fig. 2).

Structure.—The region is one in which the strata have been thrown into great northeast-southwest folds from horizontal pressure applied in a northwest-southeast direction. In addition to the folding, continuation of the same compressive forces resulted in fracturing and faulting the strata over most of the area. To the northwest of the Coosa valley the area is one of open folds, and faulting is less conspicuous. Folds of the anticlinal, synclinal and monoclinal types are represented in many examples of northeast-southwest-trending ridges preserved in the harder and more resistant rocks.

In the region to the south and southwest of Rome, the structure is more complicated, largely by reason of the folding having been quite or entirely obliterated by subsequent faulting, and by deposition-overlaps and abrupt lithologic changes.[1] Two classes of faults, which differ materially from each other, characterize the area. These are designated by Hayes[2] as (*a*) major thrust faults, and (*b*) minor-thrust faults.

The major-thrust faults are characterized by great horizontal displacement and low inclination of the fault-plane. Three faults of this type have been recognized and described by Hayes[3] in this area, namely, the Coosa, Rome and Cartersville overthrust faults. In the case of the Cartersville fault, rocks of probable Algonkian age and belonging to the Crystalline-

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[1] Hayes, C. W., *Bulletin, Geol. Soc. of America*, 1894, vol. v., p. 472.

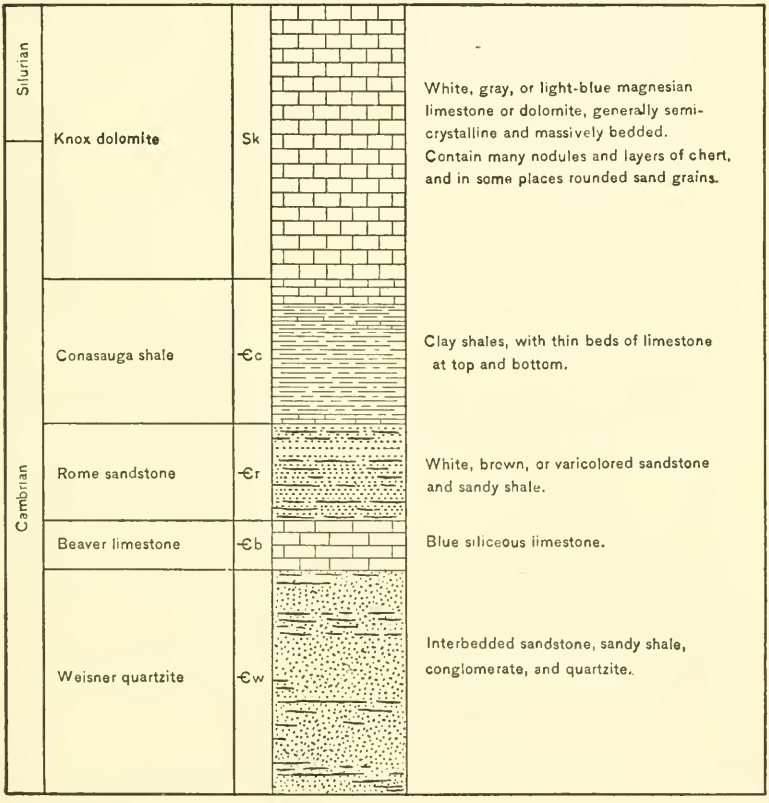
[2] *Op. cit.*, pp. 557-560.

[3] Hayes, C. W., "The Overthrust Faults of the Southern Appalachians," *Bulletin, Geol. Soc. of America*, 1891, vol. ii., pp. 141-154; "Geology of a Portion of the Coosa Valley in Georgia and Alabama," *Bulletin, Geol. Soc. of America*, 1894, vol. v., pp. 465-480.

metamorphic area of the State, have been overthrust upon Silurian rocks of the Paleozoic area. (See Fig. 3). These faults bear no relation to the manganese-deposits, and, therefore, need not be more fully described in the present connection.

The minor-thrust faults characterize the southern part of the area, especially of the area immediately south of Rome and in the vicinity of Cave Spring, and are of the ordinary Appa-

FIG. 2.


Silurian
Cambrian
Knox dolomite
Sk
White, gray, or light-blue magnesian limestone or dolomite, generally semi-crystalline and massively bedded. Contain many nodules and layers of chert, and in some places rounded sand grains.
Conasauga shale
Cc
Clay shales, with thin beds of limestone at top and bottom.
Rome sandstone
Cr
White, brown, or varicolored sandstone and sandy shale.
Beaver limestone
Cb
Blue siliceous limestone.
Weisner quartzite
Cw
Interbedded sandstone, sandy shale, conglomerate, and quartzite.

Generalized Stratigraphic Section of the Georgia Manganese-Area. (Adopted from Hayes). Scale, approximately, 1 in. = 2000 ft.

lachian type. (See map of the Cave Spring district, Fig. 9.) They have an approximate north-south direction, intersecting the main axis of the region at angles of 30 to 40 degrees, or

thereabouts. In length they vary from 3 to 8 miles, and they cut the strata at close intervals into narrow strips, forming monoclinals, which dip steeply toward the east. The faults of this type in the region already mentioned result in long and narrow strips of the underlying Conasauga shales, which form the narrow valleys penetrating southward into the Knox dolomite plateau.

For the reason that the two types of faults here distinguished are seldom found intersecting each other, the faulting is inferred to belong to different and, therefore, distinct periods of disturbance.

The Cartersville District.

One of the principal manganese-producing districts in the Southern Appalachians is in the vicinity of Cartersville, Bartow county, Georgia, about 50 miles northwest of Atlanta. Manganese-mining in this district dates back as early as the year 1866, when 550 tons of the ore are reported to have been mined.[1] From that time to the present the Cartersville district has been one of the three principal producers of manganese in the United States. Excepting the Cave Spring district, the entire production of manganese in Georgia has been from this district.

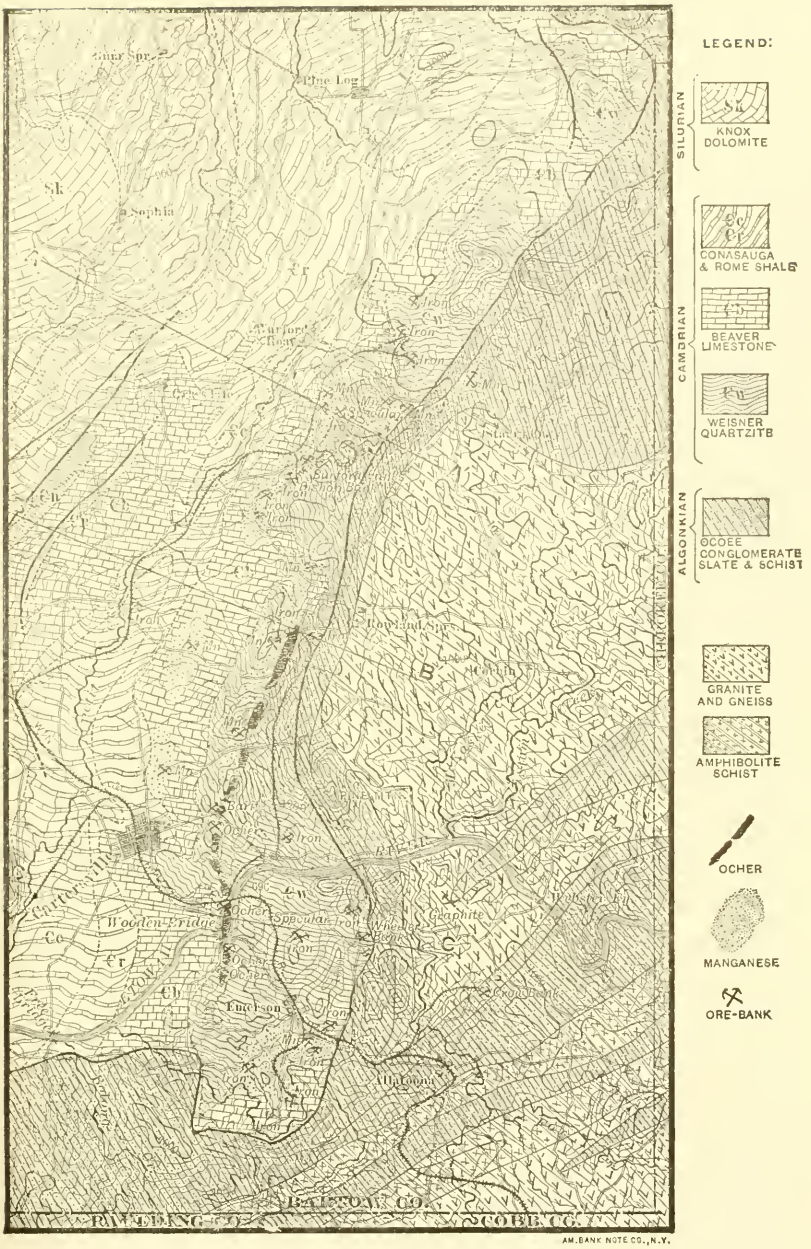
The older crystalline and metamorphic rocks occupy the east half of the area shown on the map (Fig. 3). The Paleozoic formations of the valley province occupy the west half of the mapped area. The line separating the two groups is an irregular one, marking the position of the Cartersville fault.

The succession of formations in ascending order, on the west side of the Cartersville fault, is as follows:

Silurian . .	Knox dolomite. Cherty magnesian limestone.
Cambrian,	Conasauga shale. Olive clay shale, chiefly.
	Rome shale and sandstone. Purple, white, green and brown sandstone, and interbedded sandy shale.
	Beaver limestone. Blue siliceous limestone.
	Weisner quartzite. Quartzite, coarse conglomerate and micaceous shale.

[1] *Mineral Resources of the United States*, 1885, p. 329.

FIG. 3.



Contour interval 100 ft. datum, mean sea-level

Geological Map of the Cartersville District, Georgia, Showing the Distribution of the Ore-Deposits. (C. W. Hayes, *Trans.*, xxx., 465.)

Except the Knox dolomite, all the formations shown on the map to the west of the Cartersville fault belong to the middle and lower Cambrian. The Knox dolomite is here included entirely in the Silurian, although strong reasons appear for grouping the lower portion of this formation with the Cambrian. In Figs. 2, and 9, the Knox dolomite is designated as partly Cambrian and partly Silurian.

The Paleozoic Rocks of the Cartersville District on the West Side of the Fault.

The Weisner Quartzite.—The Weisner quartzite is in contact on the east side with the Cartersville fault. The principal area of the quartzite occupies the middle portion of the map as an irregular strip, having an approximate north-south extension of about 15 miles and, in width, varying from 1 to 3 miles. It is composed principally of a fine-grained quartzite, with additional bands of a fine-grained conglomerate and micaceous shales. Wherever exposed, the formation shows evidence of intense folding, fracturing and crushing. The absence of satisfactory exposures, added to the complex folding of the beds, prevents an accurate estimate of its total thickness, but it is probably not less than 2000 to 3000 ft. thick in this locality, as stated by Hayes.

Hand-specimens of the Weisner quartzite, carefully collected by the writer from the numerous outcrops of the entire area exposed in Georgia were thoroughly mixed and prepared as one sample, a representative part of which yielded, at the Pratt laboratory, Atlanta, the results shown below.

Analysis of Weisner Quartzite, Cartersville District.

SiO_2,	90.36
TiO_2,	0.07
Al_2O_3,	1.52
Fe_2O_3,	0.57
CaO,	0.27
MgO,	0.27
MnO,	None
Na_2O,	0.43
K_2O,	0.16

H_2O at 100° C.,	None
H_2O above 100° C.,	0.31
FeS_2,	1.50
$BaSO_4$,	4.46
Total,	99.92

The Beaver Limestone.—The main belt of the Beaver limestone lies along the western base of the Weisner quartzite ridges. A second, but smaller, area of the limestone extends from Grassdale southward to the line of the Western and Atlantic railroad, and is indicated near the western margin of the map. Exposures of the fresh limestone are rarely seen, since it is readily soluble, resulting in the insoluble residue forming a thick mantle of deep-red soil. The formation is readily traced, however, from the resulting red soil. Fragments of the quartzite in all stages of decay, derived from the adjacent higher quartzite ridges on the east, are admixed in some quantity with the decay derived from the limestone. The few exposures of the limestone met with indicate a semi-crystalline, gray, magnesian limestone, containing, as Hayes states, occasional masses of chert, becoming shaly in places. Hayes[1] estimates the thickness of the limestone to be not less than 800 to 1200 ft.

These two formations, the Weisner quartzite and Beaver limestone, are of considerable importance as ore-producing formations in the Cartersville district, as a majority of the ore-deposits are associated with them. The manganese-ores occur with about equal frequency in the residual decay of the two formations.

The Conasauga Shale.—Next above the Beaver limestone is the great thickness of the Rome and Conasauga sandstone and shale (Oostanaula shales of Spencer). The main outcrop of the shale occupies the northwestern part of the mapped area. A continuous band of the exposed shale extends southward from the main outcrop to the line marking the position of the Cartersville fault. The southern half of the band, which extends several miles in a north, south and west direction from Cartersville, is greatly widened.

[1] *Trans.*, xxx., 406 (1901).

Petit creek, one of the principal streams in the area mapped, takes its rise in the Conasauga shales some 10 miles north of Cartersville, and maintains its entire course southward to the Etowah river on the soft shales.

In lithologic character, the shales vary from very fine-grained aluminous or clayey rocks to somewhat siliceous shales and sandstone, with the aluminous type predominant. Numerous exposures show interlayered thin- and thick-bedded limestone with the shale. In color, the shales vary from light-drab and yellow to dark blue slaty, best described, as a whole, as olive shales. The weathered shale is usually tinted some light shade of red, in marked contrast to the deep red decay of the limestone. The shales are much fractured and crushed from the effects of intense pressure metamorphism. The thickness of the formation is placed between 1500 and 3000 ft.

The following analyses give a general idea of the chemical composition of the shales in this region:

Analyses of Middle Cambrian Shales, Cartersville District.

	I.	II.	III.	IV.	V.
SiO_2, (free sand), SiO_2, (combined),	55.02	52.82	62.30 / 9.30	39.20 / 19.40	52.82
Al_2O_3,	21.02	26.17	11.50	18.05	26.17
Fe_2O_3,	5.00	9.46	5.59	8.31	9.46
FeO,	1.54	----	----	----	----
MnO,	trace	----	0.60	----	----
CaO,	1.60	trace	none	none	trace
MgO,	2.32	1.08	1.30	1.55	1.08
Na_2O,	0.81	0.20	0.35	0.33	0.20
K_2O,	3.19	2.71	4.20	4.63	2.71
H_2O at 110° C.,	2.44	0.23 (hygr.)	0.15 (hygr.)	0.40 (hygr.)	0.23 (hygr.)
H_2O above 110° C.,	5.65	7.00	3.80	7.60	7.00
TiO_2,	0.65	----	1.10	0.68	----
P_2O_5,	0.06	----	----	----	----
BaO,	0.04	----	----	----	----
SrO,	trace	----	----	----	----
Li_2O,	0.03	----	----	----	----
SO_3,	0.02	----	----	----	----
Cl,	trace	----	----	----	----
CO_2,	0.83	----	----	----	----
Carbonaceous matter,	0.32	----	----	----	----
Total,	100.54	99.67	100.19	100.15	99.67

I. Middle Cambrian shale. Coosa Valley, near Blaine, Cherokee county, Alabama. H. N. Stokes, analyst. *Bulletin No.* 163, *U. S. Geol. Survey*, 1900, p. 283.

II. Oostanaula (Conasauga) shales, about 2 miles northwest of Cartersville, Bartow county, Georgia. J. M. McCandless, analyst. "Paleozoic Group," *Geol. Survey of Georgia*, 1893, p. 285.

III. Light-colored hydro-mica shale on the ridge above the Etowah river iron bridge, south of Cartersville. On the border of the metamorphic zone. "Paleozoic Group," *Geol. Survey of Georgia*, 1893, p. 284. J. M. McCandless, analyst.

IV. Light-red shale, in the valley 1 mile southwest of Cartersville. "Paleozoic Group," *Geol. Survey of Georgia*, 1893, p. 284. J. M. McCandless, analyst.

V. Oostanaula (Conasauga) shales, about 2 miles northwest of Cartersville. "Paleozoic Group, *Geol. Survey of Georgia*, 1893, p. 285. J. M. McCandless, analyst.

The Knox Dolomite.—The Knox dolomite lies next above the Conasauga shales. The lower beds are probably Cambrian, but, owing to the paucity of fossils in them and the striking uniformity in lithologic character, the entire formation is here classed as Silurian. Hayes says:[1]

"From the few fossils which have been found, it appears probable that a transition from Cambrian to Silurian occurs in the lower third of the formation, but it is generally impossible to determine this line of division. . . ."

It is a massively-bedded, semi-crystalline, gray-magnesian limestone, containing abundant nodules and layers of chert, and is one of the most persistent formations in the Southern Appalachians.

Weathering of the dolomite, by removal in solution of the soluble calcium and magnesian carbonates, has covered the limestone surface by a prevailingly thick mantle of insoluble siliceous clays abundantly admixed with chert-fragments and masses. The residual clays derived from the dolomite are often light in color, containing comparatively small amounts of iron oxide. In many places, however, the clays derived from the limestone are deep-red ferruginous clays, containing much iron oxide. The proportion of clay to chert varies considera-

[1] "Geologic Atlas of the United States," Rome Folio, *U. S. Geol. Survey*, 1902, p. 3.

bly, but the quantity of chert admixed with the clay is always large. It is by means of its residual material, especially the chert nodules and masses, that the Knox dolomite is often traced, for exposures of the fresh rock are seldom seen except along the stream-courses.

The magnesian limestone has an estimated thickness of 3000 to 5000 ft. As a producer of manganese-ores, the Knox formation is, perhaps, of less importance in the immediate Cartersville district than either the Weisner quartzite or Beaver limestone. Excepting the Cartersville district, the Knox dolomite is one of the most important ore-producing formations in the Georgia Paleozoic area, as the extensive accumulations of bauxite and a part of the iron- and manganese-deposits are associated with it.

The numerous chemical analyses made from specimens collected from the Knox formation over many localities in Georgia show its composition to vary within the following limits:

SiO_2, 3.75 to 7.25; Al_2O_3 and Fe_2O_3, 1.24 to 1.76; $CaCO_3$, 34.07 to 53.44; and $MgCO_3$, 36.32 to 55.74 per cent.

The Older Crystalline and Metamorphic Rocks of the Cartersville District on the East Side of the Cartersville Fault.

Several types of crystalline, metamorphic rocks are represented which show wide variation in composition and, probably, in age. Of these, the Corbin granite-area, which occupies the middle eastern portion of the map (Fig. 3), is the most extensive. As mapped, this granite mass is a roughly oval-shaped area extending from Stamp Creek P. O. on the north to the line of the Western and Atlantic railroad on the south, and continuing eastward into Cherokee county. The granite is a coarse-grained porphyritic rock, presenting a distinct augen-gneiss facies in the border-portions. It is composed of large, microcline phenocrysts imbedded in a ground-mass of blue quartz, plagioclase feldspar, augite and mica. Its composition is shown in the following analysis, made by Dr. H. N. Stokes,

of specimens collected by Mr. A. H. Brooks of the U. S. Geological Survey, 1 mile east of Rowland, Bartow county, Georgia:

Analysis of Granite, Cartersville District.

SiO_2,	67.98	TiO_2,	0.84
Al_2O_3,	14.84	P_2O_5,	0 34
Fe_2O_3	1.00	MnO,	trace
FeO,	3.15	BaO,	0.20
MgO,	0.91	SrO,	trace
CaO,	2.17	Li_2O,	trace
Na_2O,	2.66	S,	0.08
K_2O,	4.76	Cl,	trace
H_2O+,	0.14	F,	trace
H_2O-,	0.49	C (Graphite),	0.21
		Total,	99.77

Brooks has given the following petrographic data on the granite from this locality:

"Contains microline, some plagioclase, abundant pyroxene, partly altered into chiefly uralite and chlorite, some biotite with frequent inclusions of rutile, much blue vitreous quartz, apatite, zircon and magnetite."[1]

In places, the border-portion of the granite mass is overlapped by a coarse feldspathic conglomerate whose mineral constituents were evidently derived from the granite, since the microcline and the blue quartz of the granite enter largely into the composition of the conglomerate. In other places a series of black graphitic slates are in contact with the granite. No fossils are known to occur in the conglomerates and slates, and on account of their appearance of extreme age, Hayes[2] has grouped them as Algonkian (Ocoee).

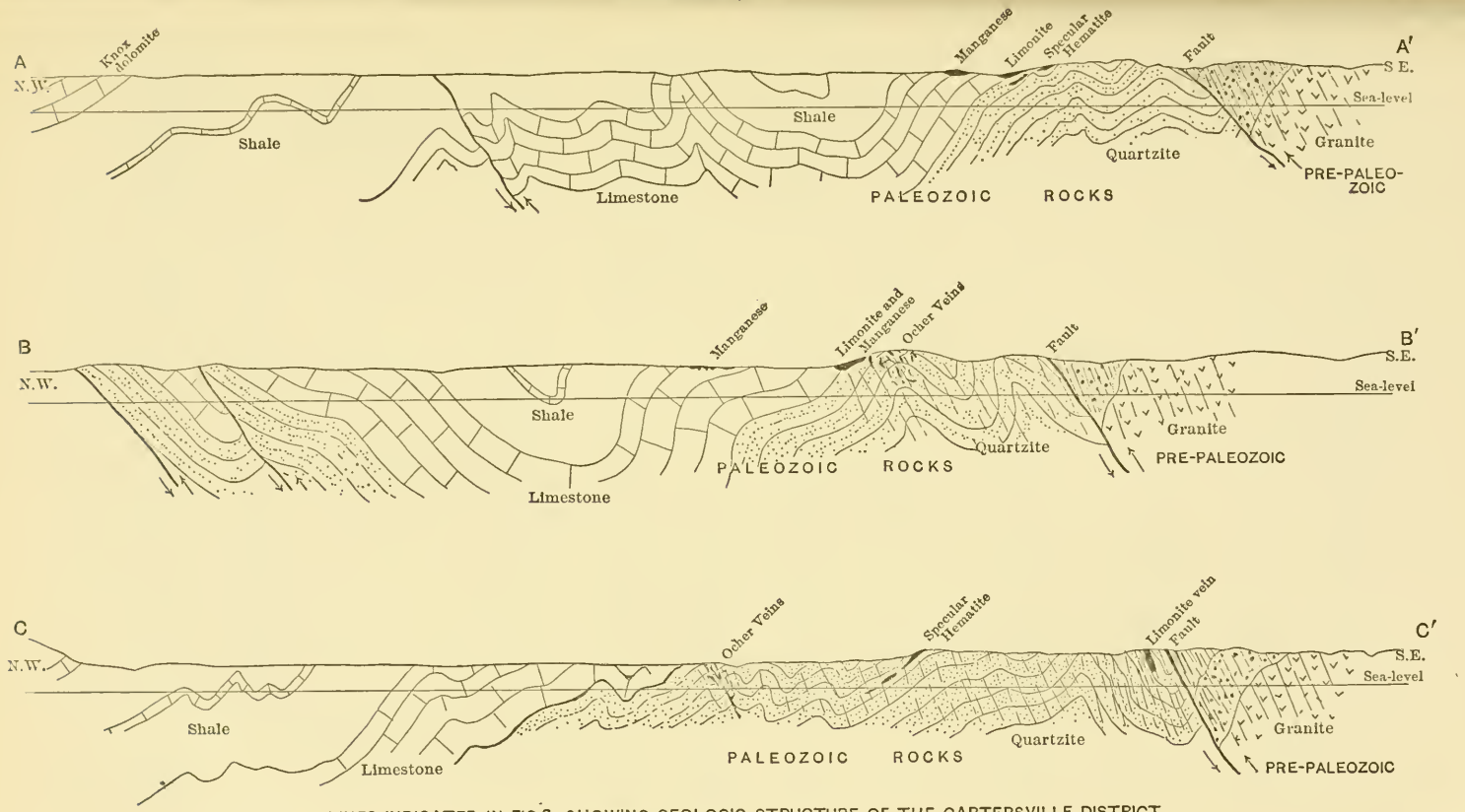
To the south of the Corbin granite-area, the conglomerates and slates increase in metamorphism and apparently pass into schists and gneisses, whose origin, whether igneous or sedimentary, is unknown.

The extreme southeast corner of the map (Fig. 3) comprises narrow belts of granite, gneiss and hornblende (amphibo-

[1] Clarke, F. W., *Bulletin, U. S. Geol. Survey*, No. 168, 1900, p. 55.

[2] Hayes, C. W, *Trans.*, xxx., 408 (1901).

FIG. 4



SECTIONS ON LINES INDICATED IN FIG.3., SHOWING GEOLOGIC STRUCTURE OF THE CARTERSVILLE DISTRICT.

Scale, horizontal and vertical 1 in. 5000 ft.

Section on Lines Indicated in Fig. 3, Showing Geologic Structure of the Cartersville District. (C. W. Hayes, *Trans.*, xxx., 407.)
Scale, horizontal and vertical, 1 in. = 5000 ft.

lite) schist. According to Hayes,[1] both diabases and diorites are represented in the area. Diorite is regarded as the commonest type of rock, and it is now mostly altered into the amphibolite schist.

Structural Features.

It is only necessary in this paper briefly to call attention to the broader structural features of the district, since the manganese deposits are limited to the residual clays of several of the formations, and only in a very general way do they show any relations to the structure In his paper on the iron ore-deposits of the district, Hayes has discussed in some detail and in a most excellent manner the structure of the region, to which paper the reader is referred for further details.[2]

The area has been one of intense and prolonged disturbance (compressive forces) operating in a northwest-southeast direction, resulting in profound alteration of the rocks,—their folding, crushing and fracturing. In places, some of the rocks, originally unlike, are so profoundly altered that they are with great difficulty distinguishable at present. On the east side of the fault-line the rocks are mashed and squeezed, and the slaty and schistose structures strongly developed, while on the west side the rocks are complexly folded and fractured. In addition to the folding, the Weisner quartzite especially has been much crushed and in places brecciated, probably indicating faulting. Some of the more massive formations, such as the Knox dolomite, resisted the folding to a greater degree than others.

The overthrust fault which separates the older crystalline rocks from the Paleozoic sediments is the principal structural feature of the region Its position is shown on the accompanying map (Fig. 3), where it is observed to pass some distance to the east and south of Cartersville, from which town it derives its name. Its line of contact is here marked by the rocks of the Ocoee series on the east side, brought next to the rocks of the Cambrian on the west side.

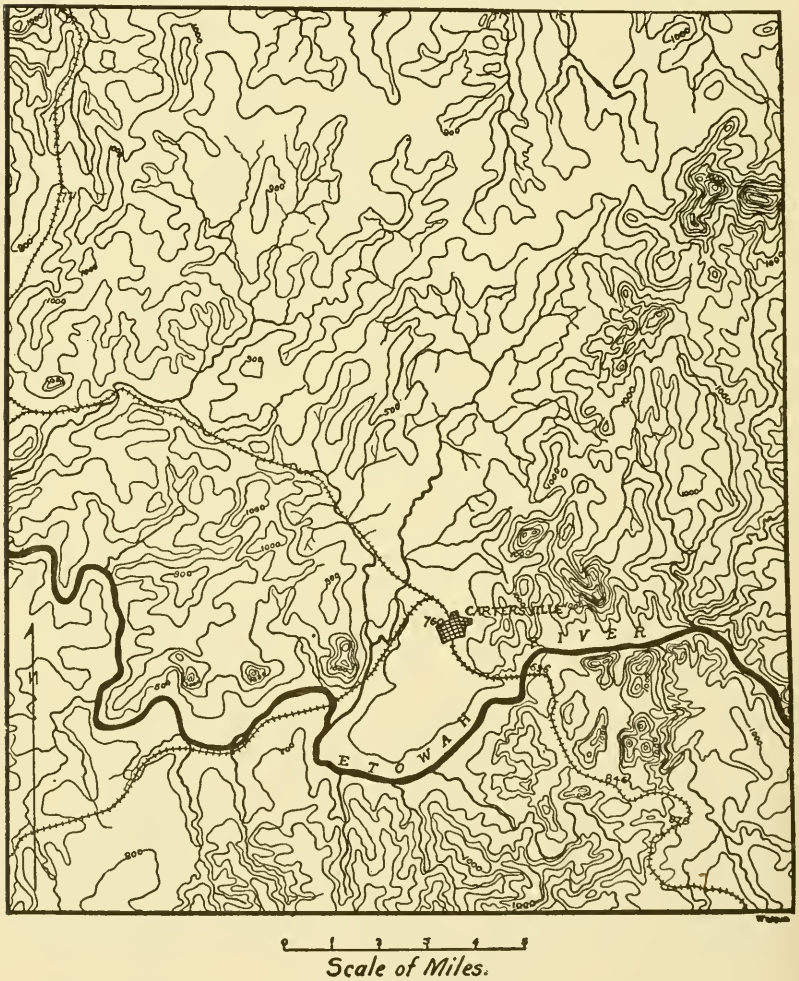
[1] *Ibid.*, p. 408.

[2] *Op. cit.*, pp. 403-419.

The Manganese Ore-Deposits of the Cartersville District.

Mode of Occurrence of the Ores.—The manganese-ores occur imbedded in the heavy mantle of residual material derived from the decay of the Beaver limestone and the Weisner quartzite, and they have nearly equal distribution in the decay de-

FIG. 5.



Topographical Map of the Cartersville District, Georgia. (Cartersville Topographic Sheet, *U. S. Geol. Survey*). Contour-interval, 100 ft.

rived from the two formations. The decay of the Weisner quartzite is a gray to yellow siliceous clay admixed with fragments of the quartzite in all stages of decay; that of the Beaver limestone is a deep-red clay, less siliceous than that derived from the Weisner formation, admixed with some chert-fragments; and, near its eastern margin in contact with the Weisner quartzite, additional fragments of the latter rock are found.

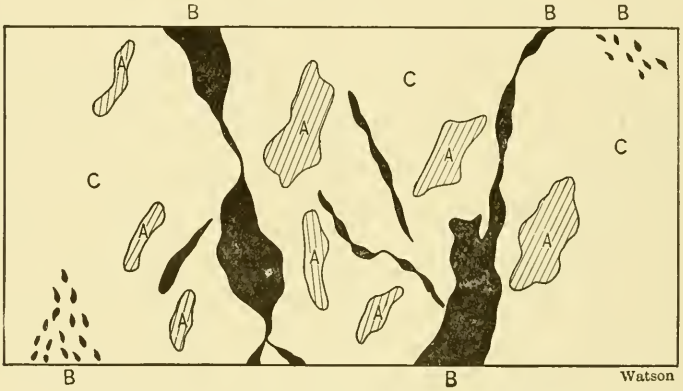
The ore is distributed through the clays in an extremely irregular manner in the form of pockets or lenticular masses, rarely as distinct beds; veins and stringers cutting the clays in all directions; as single nodules or concretionary masses assembled in the clays; and as small disseminated grains scattered through the clay. In places, the ore-distribution in the clays conforms in a general way to the bedding of the inclosing clays; usually, however, this is obscured and the ore-bodies indiscriminately cut in all directions. The pockets vary widely in size and number. They range in size from mere nests to bodies 6 and more ft. thick and more than 30 ft. long, and in extreme cases may yield several hundred tons of ore. Rarely are they composed of solid ore free from the surrounding clay, the usual form being that of somewhat thickly-studded nodules in the clays. They may occur close together, or far apart, and are usually not in any way connected; although in many cases irregular stringers and small veins are observed to lead from one pocket to another. (See Figs. 6 and 7.)

The ores are never entirely free from inclusions and admixtures of the inclosing clays, a condition which naturally results from their method of accumulation. Some of the ores are, of course, freer from these mechanical impurities than others, and in the purest ore the included grains of silica and the adhering clay are reduced to a minimum. The proportion of clay to ore is usually larger than in the closely associated brown iron-ores.

Depth of the Residual Decay.—The depth of the rock-decay varies greatly, and it is dependant, other things being equal, on the character and composition of the rock, and on the disposition of the rock-strata. The quartzite of the Car

tersville district has been much broken and crushed, and it is thrown into a series of narrow, more or less steep folds or ridges, whose surface is everywhere covered to some depth with its residual decay. Reefs of the hard and fresh rock are often exposed along the crests of the ridges, and to some extent exposures are frequent near the tops and along the steeper slopes of the ridges.

FIG. 6.



Section in One of the Openings on the Blue Ridge Mining Co.'s Property, near Cartersville, Georgia, Showing the Mode of Occurrence of the Manganese-Ore in the Residual Clay.

A, fragments and masses of partially decayed rock; B, manganese ore; C, residual clay.

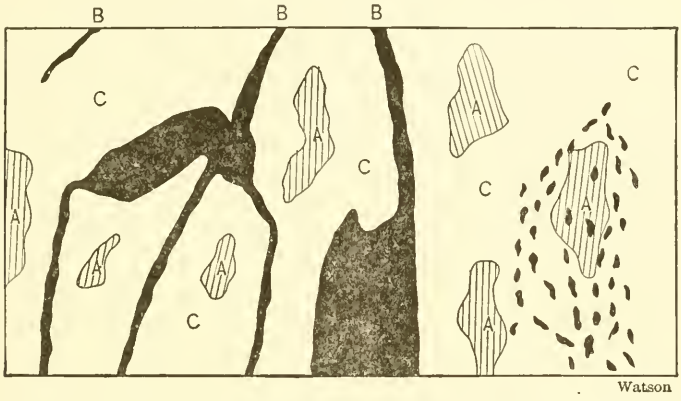
Horizontal and vertical scale, 1 in. = 17 ft.

Shafts have been sunk in several places to a depth of several hundred feet without piercing the bed-rock. Depths of 100 ft. and more in the residual mantle are common in the district. In the Chumler Hill section, about 8 miles northeast of Cartersville, several shafts have been sunk to a depth of more than 80 ft. in manganese-mining without encountering the bed-rock. (See Fig. 11.)

Kinds of Ore.—Only the oxides of manganese occur in the Cartersville district. Of these, pyrolusite and psilomelane greatly predominate, with some manganite and braunite and much of the earthy oxide, wad. These different oxides cannot always be separated, but they usually occur admixed in vary-

ing proportions. With the exception of the mineral wad, the ore is usually partially or entirely crystalline, of a dark steel-blue color, and the nodular type which prevails nearly always displays the complete or partially layered or concentric structure of concretionary masses.

FIG. 7.



Section in One of the Openings at the Dobbins Mine, near Cartersville, Georgia, Showing the Occurrence of Manganese-Ore in the Residual Clays. (Modified from Penrose.)

A, fragments and masses of partially decayed rock; B, manganese-ore; C, residual clay.

Horizontal and vertical scale, 1 in. = 10 ft.

Associated Ore-Deposits.—Extensive deposits of brown iron-ore and gray or specular hematite, yellow ocher, and to a less extent barite and bauxite occur somewhat closely associated with the manganese-ores. Of these the deposits of iron-ore and yellow ocher have been extensively mined. The bauxite and barite are of less importance, since the former is only sparingly found within the limits of the district, and the latter, while more abundant, is not sufficiently concentrated to admit of profitable working. These are again referred to at some length in a subsequent part of this paper under the origin of the manganese-ores.

Manganiferous Iron-Ores.—The beds of brown iron-ore, which is the prevailing type of iron-deposit in the district, are usually distinct from, though occurring in close relation with,

the manganese-ores. The oxides of iron and manganese are often found admixed in different proportions in the same bed. Between the two extremes of pure iron-ore and pure manganese-ore occur all gradations in the admixture of the two oxides. In some of the beds the two materials are homogeneously mixed, giving the appearance of a manganese ore when the iron is present in small quantity, and of the usual brown hematite-ore when manganese is in small quantity. In still other cases the beds of iron-ore are found incrusted in places at the surface for only a slight depth, with the oxide of manganese, which on being opened proves to be a good deposit of iron-ore and not manganese.

Analyses of the iron-ores invariably show small percentages of manganese, and conversely the manganese-ores show varying percentages of iron, with intermediate gradations in which the two oxides are present in nearly equal amount, forming a good grade of manganiferous iron-ore. These gradations are shown to some extent in the following partial analyses of samples of the ores from this district:

Analyses of Cartersville Iron- and Manganese-Ores.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Manganese, -	41.98	36.00	25,09	15.26	60.61	2.30	54.94	56.40
Iron, -	16.22	16.88	29.17	39.25	1.45	52.02	3.62	1.29
Phosphorus, -	0.227	0.14	0.155	0.193	0.052	0 24	0.034	0.158

Chemical Composition. — The hundreds of commercial analyses of the Cartersville manganese ores indicate that the ores do not differ essentially from similar high grade ores occurring elsewhere. The average in metallic manganese in the better-grade ores is uniformly high, with correspondingly low iron, silica and phosphorus. Silica will usually average low in those cases where the ore has been properly cleansed. It rarely ranges above 10 per cent., and is usually much below this, averaging from 2 to 5 per cent. Of course, in many of the lower-grade ores the silica will average considerably above 10 per cent. The phosphorus in the Cartersville ores is rarely high enough to detract from the value of the ore. The average in this ingredient for the better-grade ores of the district is

from 0.10 per cent. to 0.15 per cent., rarely rising above 0.25 per cent.

Individual Properties.—No attempt will be made in this paper to discuss or describe individual properties. These will be described in detail in a forthcoming report by the writer, to be published by the Geological Survey of Georgia. Among some of the more important properties in the district which have yielded much ore of superior quality may be mentioned the Blue Ridge Mining Company (formerly known as the Etowah Mining Company), the Dobbins, the Georgia Manganese and Iron Company, the Milner-Harris, the Satterfield, the John P. Stegall, the Chumler Hill and the Southern Mining Company. Innumerable single lots of land, distributed over all parts of the district and owned by different individuals, have produced large quantities of high-grade ore, but the lack of space forbids their mention by name.

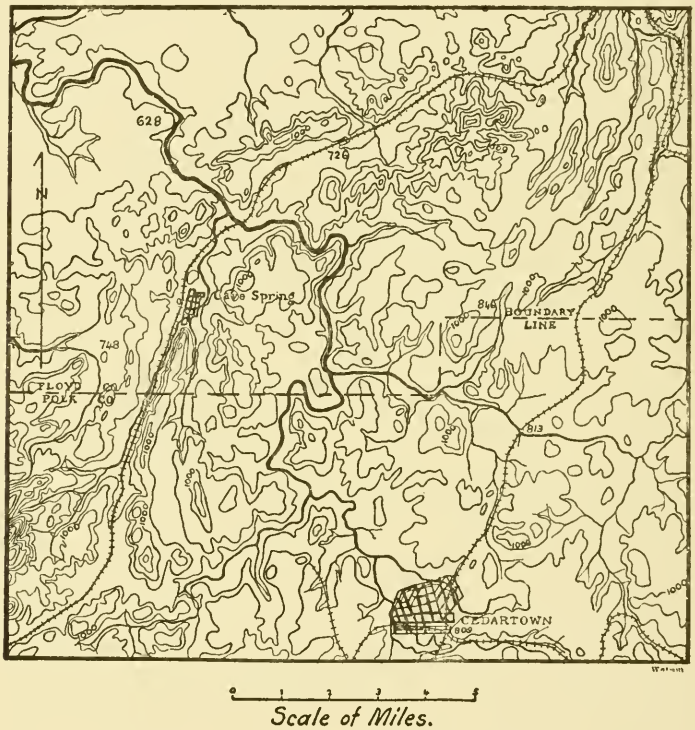
The Cave Spring District.

The Cave Spring district occupies the southwest part of Floyd county and the northwest corner of Polk county, Georgia. The town of Cave Spring, from which the district takes its name, is within six miles of the Alabama-Georgia line, about 15 miles southwest of Rome. The ore-deposits of manganese extend about 5 miles south of the town into Polk county, and continue northeastward from the town for a distance of 7 or 8 miles in Floyd county. Practically the entire production of manganese ores in Georgia has been from the Cartersville and Cave Spring districts.

Topography.—The topography of the Cave Spring area is shown on the accompanying map (Fig. 8). The region is one in which the topography is strikingly shown to be dependent on the structure and character of the underlying rocks. The strata are broken by numerous approximate north-south faults of the ordinary Appalachian type, resulting in monoclinal blocks, which dip somewhat steeply to the east and southeast. Faulting has brought the underlying shale to the surface in contact with the overlying Knox dolomite, and valleys are

etched out of the soft shale, penetrating to some extent the harder and more resistant Knox dolomite. These features are well developed in the vicinity of Cave Spring and are shown again in the northeast corner of the map (Fig. 9).

FIG. 8.

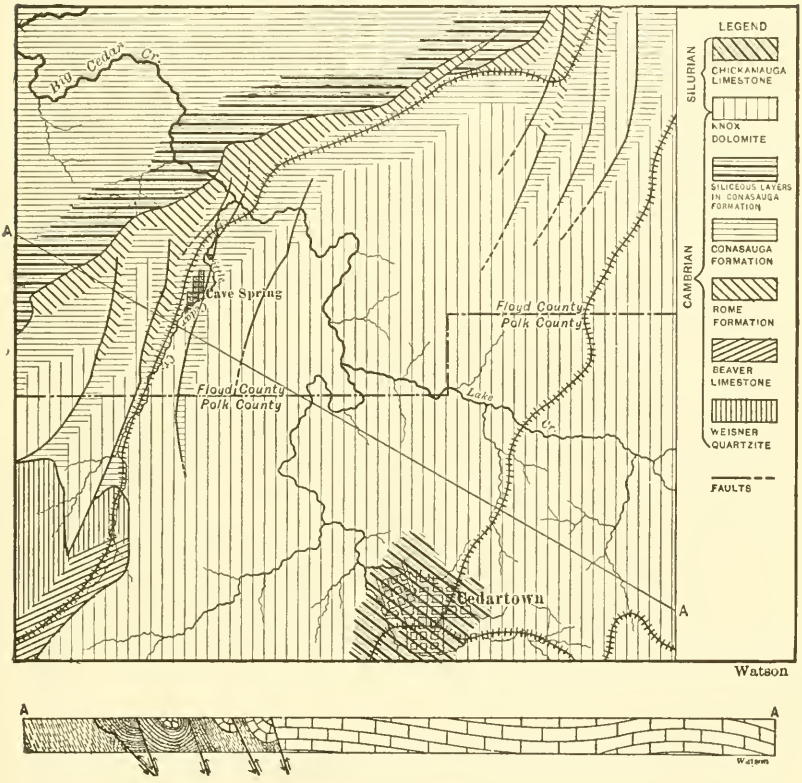


Topographical Map of the Cave Spring District, Georgia. (Topographic Sheet, Rome Folio, *U. S. Geol. Survey*). Cont ur-interval, 100 ft. Scale, 0.5 in. = 1 mile.

To the east of a line drawn through the town of Cave Spring the area is underlaid by the Knox dolomite. Surface-erosion is relatively slower over this part of the area, on account of the larger proportion of chert contained in the dolomite, than in other parts underlain by softer and less resistaut rocks. The surface is generally hilly and stands several hundred feet above the valley-floors of softer rock. It forms a

broad plateau, averaging slightly below 1000 ft. in elevation. In the extreme southwest corner of the map (Fig. 9), the hard and resistant massive Weisner quartzite is exposed as a high ridge, known as Indian mountain, which lies almost entirely in Alabama. Traces of the same base-levels are preserved in the rocks of this area as those mentioned in the region farther north.

FIG. 9.



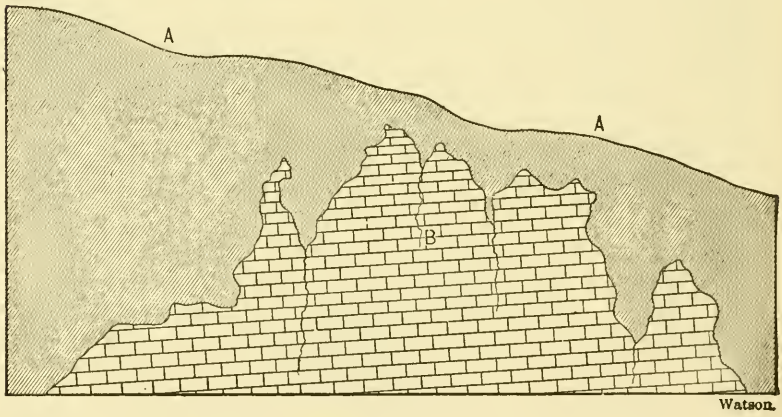
Geological Map and Section of the Cave Spring District, Georgia. (Rome Folio, *U. S. Geol. Survey.*)
Scale, 0.5 in. = 1 mile.

Stratigraphy.—The same rock-sequence is observed here as in the Cartersville area. (See Fig. 2). The same formations are represented in the two areas, with only slight varia-

tions indicated in the general character and thickness of the rocks. These formations have been described in sufficient detail under the Cartersville district, and will not be repeated here. The Knox dolomite of the Cave Spring district needs further description, since it is the only formation in the area with which the manganese-ores are associated.

The Knox dolomite is vastly the most extensive formation in the district. The percentage of chert is much larger, and the cherty masses and fragments are larger in size than elsewhere for this formation. In places, the limestone appears to be largely replaced by layers of the massive chert. Its surface is very generally strewn with the chert, and the deep-red clays derived from the limestone are heavily charged with the chert-fragments in all stages of decay.

FIG. 10.



Section in Knox Dolomite, 2 miles East of Kingston, Georgia, Illustrating Weathering of the Magnesian Limestone. (Modified from Spencer.)
A, residual clay; B, fresh magnesian limestone.

Structure.—Referring again to the map (Fig. 9), it is observed that nearly the entire southeast part is occupied by the massive Knox dolomite, which resisted the sharp folding manifested in some of the other formations. The remaining part of the map indicates numerous faults cutting the strata. These are mostly of the minor-thrust type, intersecting the Knox dolomite and the Conasauga shale, and they expose at the sur-

face the soft shales in long and narrow north-south strips, forming narrow valleys among the dolomite hills. The fault-blocks overlap each other, with rather steep dips toward the east and southeast.

Character of the Residual Decay.—The manganese ores of the Cave Spring area are entirely limited to the residual clays derived from the decay of the Knox dolomite. The decay from this formation only will be considered. The ore-bearing clay is usually of a deep-red, chocolate or brown color, with lighter tints occurring. It is soft and plastic when wet, and is generally associated with much siliceous material in the form of chert, subject to wide variation from place to place. Its depth is variable and, in places, the moderately fresh cherty limestone is exposed as broken reefs on the ridge-tops. In other places on the ridge-tops, excavations in mining expose the hard rock at depths varying from 10 to 30 ft.; and, in still other places on the same ridges, rock is not encountered at depths of 50 to 60 ft.

Massive cherty layers or beds are of more frequent occurrence in the limestone of this area than for the same formation at other points in northwest Georgia. Here the chert attains considerable thickness, and, at times, almost entirely replaces the limestone. Uusually the chert is a white or gray rock, sometimes brown, rarely black, and is often encrusted with a film or coating of the black oxide of manganese. The relation of the chert and limestone is well illustrated along the ridges to the southeast of the town of Cave Spring, where the rocks dip to the southeast, with the limestone forming the lower part of the hills and the chert the upper part.

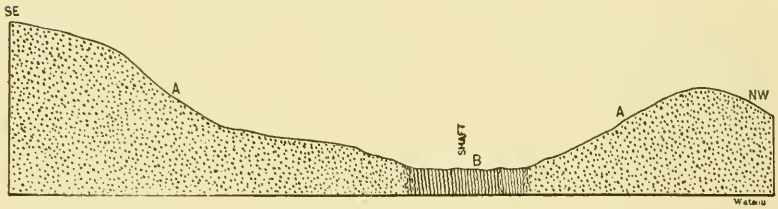
Manganiferous Chert Breccia.—The very intimate association of the chert and ore has resulted in the formation of much breccia, composed of the angular chert-fragments cemented in a manganese-oxide matrix. This seems to have originated in most cases from the infiltration of surface-waters containing manganese in solution. The occurrence of the chert-breccia beneath the clay covering is excellently illustrated in some of the excavations on the ridge above the Cedar creek valley, and

again in the openings on Reynolds mountain, 8 miles northeast of Cave Spring. (See Fig. 15.)

Manganiferous Stained Chert.—Where the chert is mixed in large proportion with the ore-bearing clays, it is often more or less stained with the manganese. This may occur as thin films or layers of the manganese oxide coating the loose chert-fragments, or as stringers and veinlets filling the cracks in the chert. The proportion of staining to chert is quite variable. In many cases it amounts to only a mere film; in others, the veins filling the cracks are quite thick. This has resulted from the free percolation of manganese-bearing waters through the loose cherty clays. Sometimes, that part of the chert not impregnated has been entirely or partially removed by decay, leaving a mass of siliceous manganese-ore of various shapes.

Occurrence of the Ores.—The occurrence of the manganese in this area is closely similar to that in the Cartersville district, already described. (See Figs. 6, 7 and 15.) The ores differ

FIG. 11



Section through the Chumler Hill Mine, Georgia, Showing the Mode of Occurrence of the Manganese-Bearing Clay. (After Penrose.)
A, sandstone; B, manganese-bearing clay.
Horizontal scale, 1 in. = ¼ mile. Vertical scale, 1 in. = 400 ft.

principally in occurrence from those in the Cartersville district in (*a*) their intimate association with the cherty beds and clays of the upper part of the Knox dolomite, in (*b*) being limited to the residual clays derived from only one formation, and (*c*) being stratigraphically above those of the Cartersville district, occurring in the clays of the Knox dolomite and not found at all in the clays of the Weisner quartzite and Beaver limestone,

which are the ore-bearing formations in the Cartersville district. The ore-occurrence in the residual clays is identical for the two districts. In the Cave Spring district the ore has been observed penetrating and filling the cracks in the partially decayed rock below in all directions with much the appearance of brecciated masses.

Associated Ore-Deposits.—Beds of brown iron-ore are frequently found in close relation with the manganese-ores. They are much more extensive and more constant than those of manganese, and the iron displays a greater tendency to a bedded form and a less tendency to the nodular form. The region in the vicinity of Cave Spring and Cedartown is probably the largest brown iron-ore-producing area in the State. A few scattered deposits of bauxite occur, but this mineral is less closely associated with the manganese than are the beds of iron-ore.

Chemical Composition.—Only the oxides of the metal occur, the principal ones of which are psilomelane and pyrolusite. Admixed with these two oxides occur varying smaller percentages of several of the other oxides, especially braunite. The following chemical analysis of specimens of the purer ore collected from the mine of Major Couper, south of Cave Spring, and analyzed by Mr. Britton, will indicate the general character of the ores.

Analysis of Manganese-Ore, Cave Spring.

Metallic manganese,	53.44
Ferric oxide,	2.83
Barium oxide,	8.62
Silica,	7.79
Alumina,	1.52
Lime,	0.08
Phosphoric acid,	0.147
Water,	1.56
Oxygen with manganese, undet., etc.,	24.013
Total,	100.000

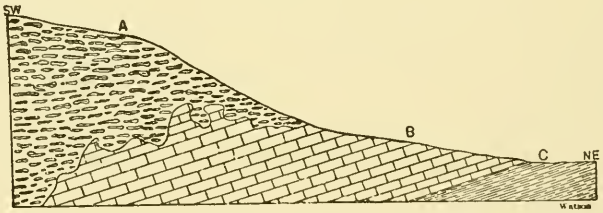
Other Manganese-Deposits of the Paleozoic Group.

Under this heading are included certain centers about which are grouped a few scattered deposits of manganese-ores.

These centers are found over parts of the northeastern, eastern and southern portions of the Paleozoic area. Many of the deposits have been worked to some extent, but in most cases the work has not progressed beyond the stage of test-openings. In some cases, no openings of any nature have been made, but strong surface-indications appear, which may or may not imply workable deposits below the surface. Small shipments of the ore have been made from a number of the openings, but as yet these scattered accumulations of the ore have proved of little or no commercial importance. Further developments in some of the localities may, perhaps, lead to important concentrations of workable ore. The mode of occurrence, association and the mineral character and form of the ores are the same as described in the Cartersville and Cave Spring districts.

The following localities include the list of these scattered ores: In the vicinity of Ligon P. O., in the extreme southwest corner of Bartow county, about 12 miles west of Cartersville; near Rome and Lindale, in Floyd county; in Big Texas Valley, 12 miles northwest of Rome, in Floyd county; the Barns-

FIG. 12



Section through the Barnsley Tract, Georgia, Showing Manganese-Bearing Chert-Bed. (Modified from Penrose.)
A, chert and cherty limestone; B, limestone; C, shale.
Horizontal scale, 1 in. = 500 ft. Vertical scale, 1 in. = 200 ft.

ley estate and vicinity, in the northwest part of Bartow county and the adjacent part of Floyd county, 17 miles northwest of Cartersville; and the Tunnel Hill district, in Whitfield and Catoosa counties.

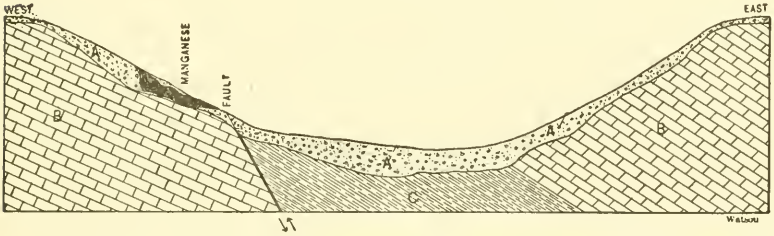
Attention is briefly called to the deposits in two of these localities.

The Lindale Deposit.—Extending southward from Lindale

is a long, narrow strip or belt of shale which marks the position of a valley for several miles in a north-south direction. The western margin of the valley marks the position of a minor-thrust fault, and to the eastward across the valley, about ¼ of a mile, the shales are overlain by the heavy beds of cherty limestone. The ridge is a low one, averaging more than 100 ft. in elevation along its highest portions, and its surface is irregular and broken by erosion. In places, it is covered with chert-fragments of all sizes in various stages of decay. (See Figs. 13 and 14.)

About ¾ of a mile south of Lindale, on the west slope of the valley and about 40 ft. above the valley-bottom, a number of openings were made in the residual cherty clay, derived from the decay of the Knox dolomite, for manganese. Red, yellow, white, buff and purple-colored clays make up the residual covering in which the manganese openings were dug. Red clay is the surface covering, and will average less than 5 ft. in thickness. The underlying yellow clay which predominates is

FIG. 13



Cross-Section of Valley, ¾ mile South of Lindale, Floyd Co., Georgia, Showing the Position of the Manganese-Deposit and the Relations of the Underlying Rocks.

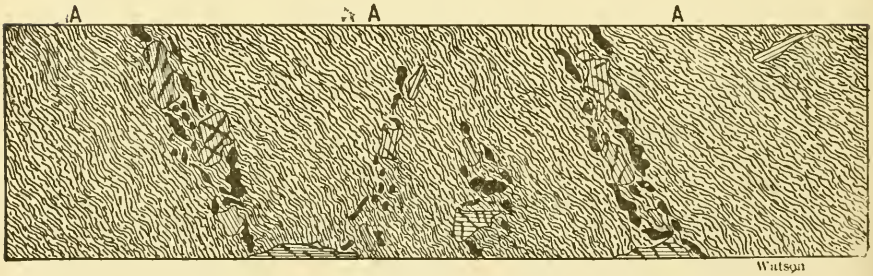
A, residual clay, containing admixed chert and partially decayed rock-fragments; B, Knox dolomite; C, Conasauga shale. The black area is manganese.

highly siliceous and freely mixed with large and small chert-fragments, usually in an advanced stage of decay. The clays usually show partial stratification, the bedding planes conforming in a general way with the ridge-slope. They thin toward the top of the ridge and are the thickest in the valley.

The ore is distributed through the clay in the form of

stringers and masses only a few inches in thickness, which cut the clay in all directions, conforming at times with the bedding-planes. Many of the stringers are composed of quartz, around and along which the ore is deposited as impregnations, incrustations, and as nodules and gravel. A goodly proportion of the gravel and nodular types of the ore is distributed through the clays without any apparent relation to the chert-fragments and masses. In most cases, however, the ore is closely associated with the chert, varying from impregnations as seams of knife-edge thickness to a ground-mass of ore cementing the partially fresh and decomposed chert-fragments. (See Fig. 15.) The form of breccia-ore commonly occurring in this locality is shown in Fig. 15. The proportion of chert to ore of the breccia-mass varies widely, from a mere film of manganese oxide, filling the cracks of the shattered chert and binding them together, to those in which the largest bulk of the mass is ore containing but few small chert-fragments.

FIG. 14



Section in One of the Openings at the Lindale Mine, 4 Miles South of Rome, Georgia, Showing the Mode of Occurrence of the Manganese-Ores.

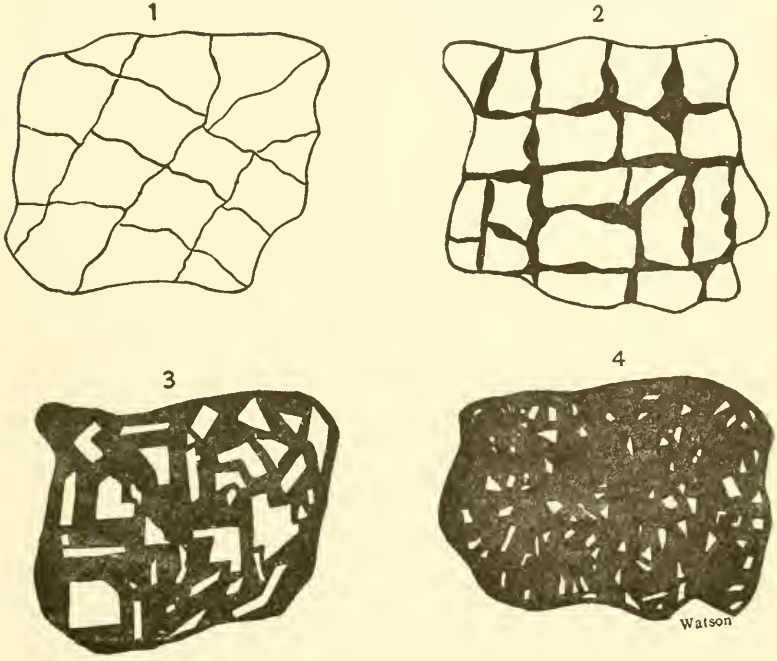
A, ore-bearing clay. The black areas are manganese. The irregular areas with straight parallel lines are fragments of chert and sandstone, the cracks of which are filled with manganese oxide.

The Tunnel Hill District.—The Tunnel Hill district includes the contiguous parts of Whitfield and Catoosa counties in the northeast part of the Paleozoic Group. In structure and topography the area quite closely resembles certain parts of the Cave Spring district already described. The rocks include shales, sandstones and limestones, and in age they range from

Cambrian to Carboniferous. Several faults of the minor-thrust type cut the rocks at close intervals. The ores are limited to the residual decay derived from an underlying long, narrow belt of Knox dolomite, marking the position of a dissected chain of ridges trending northeast-southwest. This belt of the Knox formation is included between two faults, and is in contact on the east and west sides with the Rome shales and sandstones.

In 1890, the Catoosa Mining Company made extensive preparations for mining manganese on its property, located

FIG. 15.



Drawings Illustrating the Formation of Manganese-Breccia Ore in the Lindale and Cave Spring Deposits, Floyd Co., Georgia. Manganese oxide is represented by the black lines and areas. The white areas are fragments of chert and sandstone. Attention is directed to the increase in the proportion of manganese to rock in passing from No. 1 to No. 4.

about 2 miles north of Tunnel Hill, a station on the Western and Atlantic railroad. A manganese-plant equipped with the necessary modern machinery was built, and a number of miles

of railroad were laid from the mill to the openings. Less than 30 cars of ore, including manganese and manganiferous iron-ore, were shipped.

Openings were made along the magnesian limestone ridge for a distance of 6 miles northeast of Tunnel Hill. One shaft was sunk to a depth of 210 ft. in the residual cherty clays without striking the bed-rock, and a number of others were put down to a depth of more than 100 ft. with the same result. A 150-ft. shaft is reported to have passed through manganiferous iron-ore for most of its depth.

The occurrence and character of the ore closely resemble that of the Cartersville district. The ore is mostly composed of botryoidal or kidney-shaped nodules, ranging from 1 to 12 and more in. in diameter, usually with a crystalline interior. The best exposures of the ore were observed in the cuts near the northern limits of the property.

The openings nearest Tunnel Hill show brown hematite and manganiferous iron-ore, much of which is of the breccia-type. The brown iron-ore is in close relation with the manganese, but is more abundant, occurring in the form of pockets and lenticular layers as much as 20 ft. thick. The manganese and iron occur in many places admixed as manganiferous iron ore; at other places they occur as separate and distinct ores in the same deposit; and at others still they occur as separate deposits without any admixture of each other.

Origin of the Manganese-Ores in the Paleozoic Area.

The stratigraphic position of the ores has been shown to be in the decay derived from and resting on three different formations belonging to the Cambro-Silurian, namely, the Weisner quartzite, Beaver limestone and Knox dolomite. The ores occur with about equal frequency in the decay derived from the three formations.

The character and depth of the decay and mode of occurrence, including distribution, of the ores in the clay, have already been described in some detail, and need not be repeated here. While faulting is a characteristic structural fea-

ture of the region, the distribution, occurrence and nature of the ores preclude any connection or relationship to these lines of breakage. The region is, furthermore, one of extensive and closely associated ore-deposits of different mineral types, and each type is of considerable commercial importance. These have been separately and independently studied by different geologists in recent years, and while the deposits are closely associated, they have been shown to bear no genetic relationship to each other. It is necessary here to make clearer this association of deposits.

The more important associated deposits consist of brown iron-ore, yellow ocher and bauxite. The deposits of iron-ore all contain traces of manganese, and most of the manganese contains traces of iron, but the principal deposits of the two metals are quite distinct from each other. According to origin several distinct types of limonite or brown iron-ore occur in association with the manganese in the Paleozoic area, grouped by Hayes [1] as (1) Gossan-ores; (2) Tertiary gravel-ores; (3) Concentration-deposits; and (4) Fault-deposits. Other forms of iron-ores occur, but they are of less importance within the immediate manganese districts. Only the concentration and fault-deposits concern the discussion of the genesis of the manganese accumulation.

Hayes refers to the concentration-deposits of the Cartersville district as follows: [2]

"At various times these valleys [limestone] have received the drainage not only from the adjacent quartzite and limestone, but probably, also, from other of the valley formations; and the widely disseminated iron leached from these formations during the process of decay has been transported to the limestone valley, and there concentrated upon the underlying impervious quartzite."

The principle underlying the genesis of the concentration-deposits is well expressed in the following sentence by Hayes: [3] "They may occur wherever a limestone is underlain by an in-

[1] *Trans.*, xxx., p. 411 (1901).
[2] *Ibid.*, pp. 412-413.
[3] *Ibid.*, p. 412.

soluble and impervious stratum, such as sandstone or quartzite." He further says:[1]

"Favorable conditions for this accumulation occur in northwest Georgia and Alabama, at the contact of the lower Carboniferous limestones with sandstones which sometimes underlie it, and at the contact of the Beaver limestone with the underlying Weisner quartzite."

The second type of iron-ore deposits of the area is that genetically related to the faults which intersect the strata and are designated by Hayes as fault-deposits.

The yellow ocher-deposits are closely associated with those of manganese in the Cartersville district; and also with the iron-ores of the same area. Beginning at a distance of about 3 miles southeast of Cartersville, the ocher-belt has a northward extension of 7 to 8 miles, confined exclusively to the Weisner quartzite, which has been greatly fractured and faulted. The occurrence of the ocher is entirely in the nature of replacement-deposits in the shattered quartzite,—the silica of the quartzite having been removed in solution and the hydrated ferric oxide substituted.[2]

The last type of ore-deposit in the area that needs mention is bauxite. The ore-bodies are distinct pocket deposits, having the vertical and lateral dimensions about equal, and they are inclosed in the residual clays derived from the decay of the Knox dolomite. They were first shown by Hayes,[3] and afterwards corroborated by the writer,[4] to represent accumulations of hydrated aluminum oxide in vents or springs along the lines of numerous faults which intersect the area. The source of the alumina was from below, in the underlying aluminous shales of the Conasauga (Cambrian) formation, and was taken in solution by hot ascending acidulated waters circulating along the lines of fracture.

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[1] *Ibid.*, p. 412.

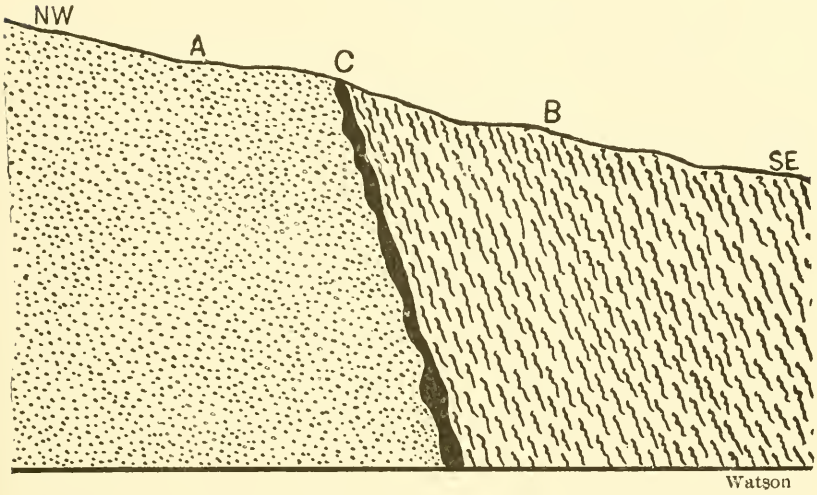
[2] *Ibid.*, pp. 415-418.

[3] Hayes, C. W., *Sixteenth Annual Report U. S. Geol. Survey*, 1895, Part III., pp. 587-591.

[4] Watson, Thomas L., *American Geologist*, 1901, vol. xxviii, pp. 25-45.

Enough detail has been given to show the non-relationship genetically between the manganese and the other ore-deposts. We must look, therefore, to an independent theory for the genesis of the manganese. The theory which best accords with the facts as the writer has interpreted them is, with some modification, that essentially outlined previously by Penrose.[1] It

FIG. 16.



Section through the Stratham Tract, near Draketown, Georgia, Showing Mode of Occurrence of the Ores.

A, banded quartzite with magnetite and some pyrite; B, decayed mica-schist, in which the planes of schistosity are perfectly preserved; C, ore, including manganese and manganiferous iron-ore, magnetite and limonite.

satisfactorily explains (1) the source from which the manganese was derived; (2) the method of solution, transportation and precipitation of the manganese; and (3) the process of its local accumulation.

1. *Source of the Manganese.*—The immediate source of the manganese was from the rocks from which the residual decay inclosing the ores was derived by weathering. Accumulation was not entirely limited, perhaps, to the manganese contained

[1] Penrose, R. A. F., 'Manganese: Its Uses, Ores and Deposits," *Annual Report Geological Survey of Arkansas*, 1890, vol. i., p. 539 *et seq.*

in any single formation in whose residual decay the ores now exist, but was derived from any formations containing this element, formerly covering the one in which the ores are now found. There is field-evidence in certain areas to support this statement.

As shown from the general geologic distribution and mode of occurrence of the ores discussed above, the source of the manganese could not have been from rocks underlying those in whose residual decay the ores are now inclosed.

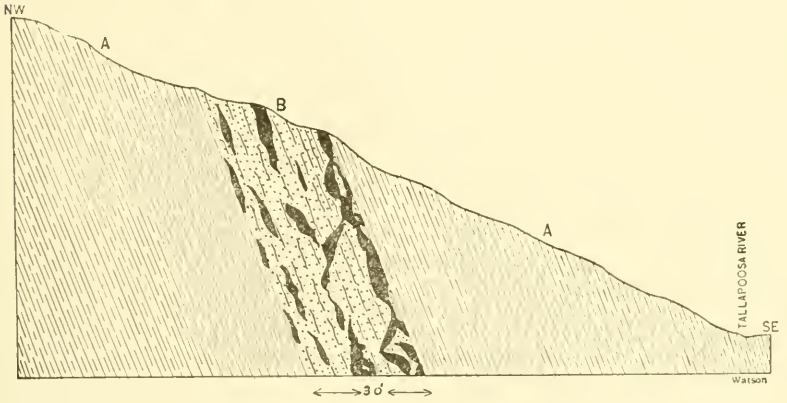
Microscopic study of a number of thin sections prepared from hand-specimens of the quartzite, collected by the writer from all parts of the quartzite area, failed to disclose any mineral substance that could be definitely referred to manganese in any mineralogical form. In order to further test the absence or presence of manganese in the quartzite, large fragments were chipped from each hand-specimen, mixed and powdered as one sample. From this bulk of powdered quartzite, a sample was carefully taken and subjected to a chemical analysis, searching particularly for manganese. The analysis showed no manganese (see analysis on page 161), which confirms the microscopic study. It would not be safe to conclude from a single analysis, though made from a sample prepared from hand-specimens of the rock taken over all parts of the area, that manganese was entirely absent from the formation. When added, however, to similar results from microscopic study, the two greatly strengthen such an inference. If these results should later prove conclusive, the source of the manganese in the decay of the quartzite must then have been from once-existing overlying formations, from which, upon weathering, the manganese was concentrated by chemical and physical conditions obtaining; or, else, the manganese now found in the decay of this formation was originally limited to that part of the formation reduced to decay.

The Paleozoic rocks are bordered on the east and south in Georgia by older crystalline rocks from which the former rocks were largely derived. These crystalline rocks, made up in part of original igneous masses and in part of original sedimentaries,

are composed of numerous complex manganese-bearing silicates. It was from these older crystalline rocks, during decay, that the manganese is believed to have been originally derived.

2. *Solution, Transportation and Precipitation of the Manganese.*—Assuming that the original source of the manganese

FIG. 17.



Section through the Westbrook Tract, Paulding Co., Georgia, Showing the Mode of Occurrence of the Ores.

A, mica-schist, partially decayed, highly schistose; B, banded quartzite, 30 ft. wide, cut by quartz-stringers containing the ore, which includes manganese, manganiferous iron-ore and magnetite.

was from the older crystalline rocks to the east and south, it remains to show how the manganiferous material reached its present form and position.

The crystalline rocks of Georgia are composed chiefly of granites, gneisses, schists and basic igneous masses, and they are everywhere deeply decayed,—buried under a thick covering of their residual clays. The essential minerals in these rocks are silicates, many of which are manganese-bearing. Decay in this southern region has been promoted largely by chemical changes in the mineral constituents of the rocks, resulting in mineralogical combinations of simpler and more stable form, totally different from the original forms. The combined action of atmospheric oxygen, water, carbonic and organic acids, and to a less degree, perhaps, certain inorganic acids, has been the

principal agent involved in the chemical decay of the rocks. Accompanying such changes, the metallic bases of the silicates combine with the various acids and are removed in solution as salts of these acids, the insoluble parts of the minerals remaining where formed, to make up the residual mantle. Manganese, with other of the base-forming elements, is thus removed in solution by the streams, and under favorable conditions of oxidation finally precipitated with the sediments on the floor of the water-bodies into which the streams drain.

Definite evidence from field-study in this area, by the writer, is lacking to indicate the exact form in which the manganese was laid down in the rocks, whether as carbonate or oxide or both.

After examination of the chemical behavior of manganese, Dunnington [1] calls attention to the probability of manganese-sulphate having taken an important part in the formation of deposits of manganese-ores. In view of the results from this examination he says: [2]

"It appears possible that many deposits of manganese in calciferous rocks owe their formation to the action of solutions of sulphates, and possibly an illustration of such action is presented in the manganese-deposits of Crimora, Augusta county, Virginia. . . ."

Professor Dunnington then outlines the conditions under which he conceives the Virginia deposits to have been formed.

3. *Local Accumulation of the Manganese.*—If, as indicated, the manganese was regularly or irregularly disseminated in a finely divided state through the limestones and quartzite in a greater or less quantity, then some secondary action or process must explain their present local accumulation. Segregation to any appreciable extent, if at all, of the finely disseminated particles of manganese does not appear to have taken place in the original unweathered rock. The agencies which promoted the decay of the rocks inclosing the manganese particles were

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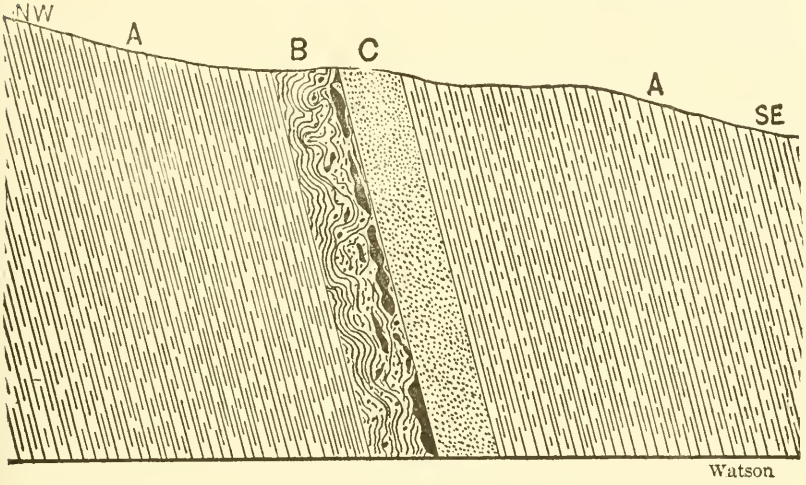
[1] Dunnington, F. P., "On the Formation of Deposits of Oxides of Manganese," *Amer. Journ. Sci.*, 1888 (3 s.), vol. xxxvi., pp. 175-178.

[2] *Ibid.*, p. 177.

those involved in the accumulation of the ores in their present concentrated form. The process involved in the local accumulation was largely one of resolution of the manganese by the acidulated surface-waters and its reprecipitation in another position in the residual clays.

The irregular distribution of the ores, both laterally and vertically, in the residual clays; the frequency with which the ore-bodies are observed to cut across the bedding of the inclos-

FIG. 18.



Section through the Blue Ridge Mine, Fannin Co., Georgia, Showing the Mode of Occurrence of the Manganese and Iron-Ores.

A, partially decayed mica-schist, grading into quartz-schist in places; B, manganese and iron oxides, distributed through the decay of the mica-schist. The black dots and areas are the ores; C, jasper-like quartz.

ing clays, and without regard to orientation in any direction; the invariable presence of greater or less quantities of included quartz-grains and other particles of siliceous material irregularly distributed through the nodules and masses of ore, of the same character as that composing the inclosing clays; the concretionary nodular and stalactitic forms of the ore; and its prevailing tendency to crystalline structure, are the most pronounced features of the ores, and are those which would result from such a process of segregation as outlined. That is, they

are secondary accumulations, resulting from chemical and physical action during the decay of the rocks containing the manganese.

Abundant masses of breccia-ore are associated to some extent with other types of the ore in all deposits, but they are especially characteristic of the lower zone of decay of the quartzite, which consists of only partially decayed and broken masses of the rock over the quartzite area. The formation of the breccia-masses is due to the downward percolation of the manganiferous solutions through the overlying mantle of decay into the cracks and crevices separating the rock-fragments and deposition of the manganese oxide. In the Cave Spring district, where broken masses and beds of chert from the Knox dolomite abound, a similar formation of chert-breccia is observed. In some instances the percolation from above has extended into the cracks of the moderately fresh rock below, with deposition of manganese forming intersecting veins in the rock.

The frequent black color of the ore-bearing clays especially noticeable near the ore-bodies, due to the presence of very finely-disseminated particles of manganese oxide, finds explanation in the precipitation of the manganese oxide from the permeating solutions. All of these associations and different types of the ore are regarded as products of secondary chemical and physical action.

Finally, this process of local concentration of manganese has its analogy in the present accumulation of manganese in the residual decay of the crystalline rocks throughout the Southern Appalachians. The writer has observed in his field-study of rock-weathering, in parts of Virginia, the Carolinas and Georgia, that, in the weathered materials of these rocks, some of whose minerals were manganese-bearing, the decay was colored black in spots from the oxide of manganese, and, frequently, knife-edge stringers of the manganese were found filling the cracks in the clays.

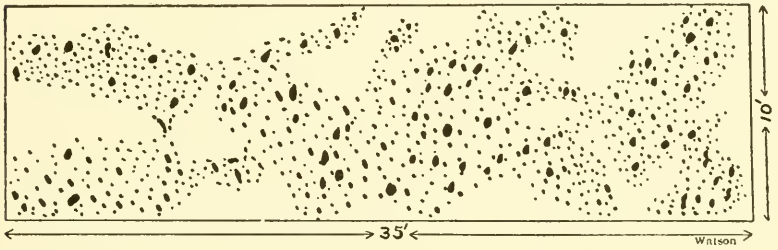
The theory as outlined above is not new, but was previously elaborated in greater detail by Prof. Penrose in his ex-

haustive and excellent volume on manganese.[1] The only point of difference between Prof. Penrose and myself, as to the Georgia ores, is that of the occurrence of some of the ore-bodies in the residual clays occupying similar positions in the original fresh rock, as stated by Penrose. The writer has not observed a single occurrence of the ores in the fresh rock in the Georgia area.

II. MANGANESE-DEPOSITS OF THE CRYSTALLINE AREA.

The position of the Crystalline area is shown on the accompanying map (Fig. 1). The area includes two physiographically distinct provinces, namely, the Appalachian mountains and the Piedmont plateau. The transition in the rocks of the plateau, along its northwest margin, to those of the mountain province

FIG. 19.



Section along the South Face of the Large Opening on the Lowe Tract, near Cave Spring, Floyd Co., Georgia, Showing the Occurrence of Manganese "Pellet"-Ore in the Residual Clay.

Black dots indicate the "pellet"-ore; white areas, deep red-brown clay derived from the Knox dolomite. No admixed chert-fragments or nodular ore contained in the clay at this point.

is indistinctly marked and is not sudden, but is, usually, gradual. Topographically, the exact limit between the two is equally difficult to define, since the elevation of the plateau near the border of the Appalachian mountain province is not sharply contrasted with that of the southeast margin of the latter province, but the slope of the one gradually passes into that of the other.

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[1] *Annual Report Geol. Survey of Arkansas*, 1890, Vol. i, p. 539 *et seq.*

The Crystalline area forms the middle belt of the State (Fig. 1). It is separated on the southeast from the Coastal Plain by the fall-line, and on the northwest it is separated from the Paleozoic area by the Cartersville fault. Its axis has a general northeast-southwest trend, and, with the exception of the extreme ten northwest counties, it occupies the entire north part of the State.

Rocks of the Crystalline Area.

With but few exceptions, the rocks of the Crystalline area include profoundly altered, original clastic and igneous masses —crystalline-metamorphic rocks. Some of the granites and most, if not all, of the more recent basic dike-rocks retain in the field their original characteristic massive structures.

Many different mineralogical types of rocks are represented. Metamorphism has been so complete in many that it is often impossible to say, with certainty, whether they were derived from original sedimentary or igneous masses. Granites, gneisses, schists, slates, limestones and quartzites or sandstones compose the principal rocks. These are cut by numerous intrusions of more recent basic igneous rocks in the form of dikes. Diabase, diorite and gabbro comprise the commonest types of dike-rocks. Hornblende- and mica-schists are the most widespread of the crystalline schists. The granites and a part of the gneisses are mica-rocks.

The entire Crystalline area is one of great complexity. The rocks are everywhere altered, intricately folded and tilted, and secondary structures induced in them. A further result of the intense metamorphism is the formation of numerous secondary minerals. The structural and age relations of the rocks of the area have not yet been worked out. With but few exceptions the rocks are geologically old, and belong to different periods of formation; some are pre-Cambrian, while others are of later age.

The Rock-Forming Minerals of the Area.

The rocks of the area comprise most of the more common rock-forming minerals and many of the rarer ones. The source

of the manganese in the crystalline rocks of the State is chiefly from the various silicates containing manganese as one of the base-forming elements. Upon decomposition of the complex silicates, the manganese is either removed in solution in the form of a soluble salt and deposited with the sediments formed elsewhere, or it is retained in part or in whole in the form of the insoluble oxide distributed through the residual decay of the original rock, *in situ*. Numerous manganiferous silicates are distributed through the rocks of the Georgia Crystalline area, among the commonest of which are certain species belonging to the amphibole, pyroxene, mica, garnet, epidote or olivine groups. Besides the silicate form of manganese, the writer has observed both the carbonate and oxide of manganese in several localities in the crystalline rocks of Georgia.

Rhodochrosite is found in Towns county, 2 miles west of Hiawassee, associated with the oxides of manganese and iron in hornblendic rocks of the corundum belt. Manganese oxide, in association with small grains and crystals of magnetite, occurs in a magnetite-quartzite schist in Haralson and Paulding counties.

Residual Decay of the Crystalline Rocks.

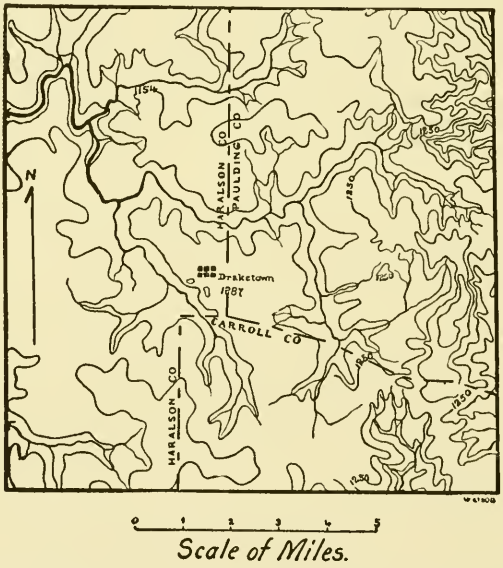
Atmospheric forces have been continuously operative on the rocks of the Crystalline area of Georgia for an indefinite period of time, resulting in the fresh rock being buried at present under a considerable depth of residual decay. Consequently, exposures of the fresh rock from which the decay was derived are seldom seen except on the steeper slopes and along the stream-courses. The mantle of decayed rock varies greatly in thickness, from a few feet to several hundred feet. Its character is equally variable, dependent mainly upon the type of rock from which it was derived and the forces promoting it.

Mode of Occurrence of the Manganese-Ores.

The lithological associations and modes of occurrence of the manganese-ores are different from those of the Palezoic area.

The ore is usually massive and often fine-granular, admixed or otherwise closely associated with iron, and is less often of the gravel and larger concretionary nodular types so characteristic of the Cartersville district and other of the Paleozoic area-deposits. Of the former occurrence the locality to the northeast of Cohutta Springs, in Murray county, and that of the Drake-town district, in Haralson and Paulding counties, are perhaps the most typical. Near the Tennessee line, in the northeast part of Murray county and 5 to 6 miles northeast of Cohutta Springs, the manganese occurs as small nests or pockets in extensive beds of iron-ore in the Ocoee (pre-Cambrian) quartzites and slates. The manganese is not entirely free from iron, and much of it is a manganiferous iron-ore of apparently homogeneous composition.

FIG. 20.



Topographical Map of the Darketown District, Georgia. (Tallapoosa and Marietta Topographic Sheets, *U. S. Geol. Survey.*) Contour-interval, 100 ft.

The ore of the Draketown district in Haralson and Paulding counties is either massive or minutely-divided manganese oxide, in a finely-banded quartzite or sandstone intercalated with mica-schist. The siliceous rock is heavily charged with

small grains and crystals of manganiferous magnetite and separate grains of manganese oxide, and in places the rock is pyritiferous. The manganese is mostly concentrated along the contact between the quartzite and schist, but contained mostly in the quartzite as massive ore carrying usually much iron, which at times almost totally replaces the manganese. (See Figs. 16 and 17.) Between the two extremes of manganese-ore containing a little iron and iron-ore with a little manganese, all degrees of admixture of the two oxides occur.

The nodular type of ore similar to that of the Cartersville district is, perhaps, best developed in the manganese-deposits occurring within the southern limits of the town of Blue Ridge, in Fannin county. (See Fig. 18.) Here the manganese is found in the residual clays derived from the decay of mica-schist near the margin of a narrow band of jasper-like quartz, which cuts the schist in an approximate north-south direction. The manganese is distributed through the clays as gravel, nodules and larger masses in nests or small pockets and stringers. The ore contains much siliceous impurity, and is in intimate relation with iron-ore, much of which has been shipped.

At other localities in the Crystalline area manganese is found, in massive and nodular forms and as a black clayey mixture of finely divided manganese oxide, in residual clays derived from the decay of hornblende- and mica-schists. The mica-schist is often garnetiferous.

The above occurrences of manganese in the crystalline rocks indicate (1) a concentration of the ore along and near the contact between certain formations; and (2) accumulation of the ore in the residual clays derived from the decay of various siliceous crystalline rocks.

Mineralogical Forms of the Ores.—The silicate, oxide and carbonate of manganese are found to some extent in the rocks of the Crystalline area. Neither the silicate nor the carbonate is of commercial importance. Manganese-bearing silicates are widely distributed among the more common rock-forming minerals of the area, and are of great importance in that they form

the source, on decay, of the workable deposits of manganese in the form of the oxide. In several localities the oxide is found, in place, in the fresh rock, but, usually, it is a secondary product inclosed in the residual clays, similar to the ores of the Paleozoic area. The manganese of both the Crystalline and Paleozoic areas of Georgia include only the oxides of the metal.

Extent of the Work and Location of the Deposits.—More or less prospecting work for manganese-ores has been done in a number of counties in the Crystalline area. The test-work has been sufficient in most cases to indicate that workable deposits of the ore do not exist, although small shipments of the ore have been made from a number of the openings in different counties.

The localities in which prospecting work has been done for manganese are widely separated and are scattered over various parts of the area which bear no apparent geological relationship to each other. The deposits are not associated with any particular type of rock, but are found in association with several widely different mineralogical types.

The counties in which manganese has been worked or tested in the Crystalline area are Murray, Fannin, Towns, Cherokee, Haralson, Paulding, Habersham and Hart. See map (Fig. 1), which shows the distribution of the ore-deposits.

Genesis of the Ores in the Crytalline Area.

Numerous openings made for manganese in different parts of the Crystalline area afforded opportunity for tracing the formation of the manganese oxides from several of the manganese-bearing silicates. Of these a manganiferous garnet and mica showed the formation of the oxide from the original silicate in both a partial and complete stage of decomposition. In each case the early stage was indicated by the original mineral being irregularly coated and spotted from decay by a mixture of the oxides of manganese and iron. The final stage showed the almost complete destruction of the original mineral, and its place filled by the black amorphous oxides of manganese and

iron. More or less stain from the oxides had extended beyond the limits of the original manganese-bearing silicate, discoloring the inclosing clays.

The source of the manganese in the Crystalline area has been mostly, if not entirely, from the various manganese-bearing silicates, which enter largely into the composition of most of the rocks. By the decomposition of the minerals composing these rocks, the base-forming elements either form soluble salts of inorganic and organic acids promoting the decay, and are removed in solution, or else the whole or a part of certain of the base-elements are converted into insoluble oxides and retained, *in situ*, to form the mantle of residual decay. In either case the process may result in the removal by solution of only a part of certain of the base-elements, iron and manganese, in the form of soluble salts, while the remainder of the same elements is retained as insoluble oxides in the residual decay. Both reactions are common in the surface zone of oxidation, as proved by recent work in rock-weathering.

Recent investigations in rock-weathering show that iron is frequently retained in the residual clays in amounts larger than that of any other constituent in proportion to the percentage amount present in the fresh rock. A loss, however, by removal in solution, in the form of a soluble salt on decay of the rock, is often shown in the iron. So far as investigation has gone, the iron is not entirely removed in any case, but a part of it remains in the form of the insoluble oxide. A like tendency is indicated for manganese when present in those rocks so far investigated.

Upon subsequent chemical and physical changes, the manganese is further concentrated in the residual clays, and the accumulation of the oxide is sometimes in quantity sufficiently large to be of commercial value.

Some of the manganese-deposits of the Crystalline area indicate that the ore has been leached from the surrounding rocks upon decay and concentrated in the clays along the contact-zones of certain formations. In only one locality in the Crystalline area, namely, the Darketown district of Haralson and Paulding

counties, has manganese been found in the form of the oxide, in place, in the original rocks. The manganese exists here partly as the free oxide in a banded quartzite, and partly as a manganese-bearing magnetite which forms a considerale percentage of the rock in places. Concentration of the manganese with iron has taken place near the margin of the quartzite in contact with the mica-schist, in quantity sufficient to yield a small amount of workable ore.

Accompanying the process of rock-decay the retention of manganese in more localized form has been promoted in places. The process is still in progress, and, accompanying it, the accumulation of manganese in those places where the conditions are favorable.

Briefly stated, then, the manganese-ores of the Georgia Crystalline area represent the secondary accumulations of the insoluble oxides of the metal supplied from the manganese-bearing silicates on decomposition, and subsequently concentrated and localized in the residual clays derived from the decay of the underlying siliceous crystalline rocks. In places, accumulation of the oxides has progressed along and near contact-zones in the rocks; in other places concentration has been in the clays and removed from contacts.

Methods of Mining the Ore.

The nature of the ore to be mined in the Georgia area is one of irregular distribution, in the form of nodules and pockets, through residual clays, which range in thickness from 25 ft. to several hundred feet. The ore-distribution varies greatly, and the deposits are limited both in depth and lateral extent; hence, the methods for operating in one place will necessarily vary, more or less, in detail from those in another. As a rule, the deposits are located on the summits and higher slopes of the hills and ridges, though there are many exceptions, for they not infrequently occupy the lower slopes and valley-bottoms.

The method of mining will depend largely upon the location of the deposits and their depth below the surface. Open

pit and cut, shaft and tunnel work are employed. These are often used together, to advantage, in the same place, especially where the ores begin at or near the surface and continue irregularly to some depth below. In such cases, open pit and cut work is used, and, from the bottom of the open work, shafts are sunk and drifts are run at different levels from the shafts. Tunneling becomes necessary in most of the steeper slope-deposits. In the lower deposits, especially those of the valley-bottoms, shafting and tunneling is most advantageously employed. In most cases of tunneling and shafting it becomes necessary, from the nature of the clays, to timber the openings in order to prevent caving. The timbering over most of the Georgia area has been poorly done, and, in many cases, put in to meet only temporary needs.

Expensive and heavy machinery is unnecessary, and the equipment should be as light and portable as possible, so that moving from one place to another, as the ore becomes exhausted, can be done speedily and at a small cost.

Preparation of the Ore.

The occurrence of the ores in the residual clays means, usually, more or less admixture of the ore with clay. Usually, the only treatment of the ore necessary before shipping is to free it from the adhering clay. Crushing and jigging are necessary in the spongy or porous type of ore, the numerous cavities of which are filled with the clay; also in those ores containing considerable free-quartz grains and cemented fragments of the rock. This is especially true of much of the breccia-ore, which is rendered marketable by materially reducing the amount of siliceous material in this method. Washing will usually suffice for cleansing the bulk of the ore. In the crushed and jigged ore, subsequent washing is also necessary.

In the early history of the manganese mining in Georgia less care was used in properly cleansing the ore than at present, and much of the ore then shipped contained large quantities of adhering clay and other extraneous material. The principal and, frequently, the only treatment was that of screening. At

that time all the washing done was by hand. The form of washer used was a revolving-cylinder perforated with holes, and fed inside by a constant stream of water. The ore was put into the cylinder through a door, the door closed and the cylinder revolved by hand until the ore was freed by running water from the clay, when the ore was removed through the same opening. The capacity of the washer was very limited, and it could be used only on a small scale. Much of the smaller ore was lost, but the larger fragments were thoroughly cleansed.

Later, a form of log-washer, similar to that used for cleansing the brown iron-ores, was introduced, and is the form of washer at present in use. Briefly, the log-washer consists of a long and stoutly-built box, of sufficient length and depth to contain the log. The box, or trough, is elevated at one end. A log or central shaft, 25 to 40 ft. long, carrying heavy iron-flanges, spirally arranged the length of the log, revolves lengthwise in the box or trough. The ore is fed at the upper end of the box, and is gradually forced by the revolving log to the lower end, where it passes out. A constant stream of water plays on the ore in the box. The constant agitation and beating of the ore by the log and the washing by water frees it from the adhering clay. Steam is the motive power.

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THE YELLOW OCHER-DEPOSITS OF THE CARTERSVILLE DISTRICT, BARTOW COUNTY, GEORGIA.

By THOMAS L. WATSON

Granville, Ohio, March, 1904.

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THE YELLOW OCHER-DEPOSITS OF THE CARTERSVILLE DISTRICT, BARTOW COUNTY, GEORGIA.[1]

By THOMAS LEONARD WATSON.

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INTRODUCTION.

Knowledge of the existence of yellow ocher-deposits in Bartow county, Georgia, dates back to the early mining of manganese- and iron-ores in the vicinity of Cartersville. Systematic mining of the ocher in this area really began, however, probably not longer than a decade back, although the date of its first working is as early as the year 1877. The district has been, for a number of years, one of the principal producers of yellow ocher in the United States; and at no period of its development have mining activities been greater and more successful than at present.

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[1] Published by permission of the State Geologist of Georgia.

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Systematic field-study of the ocher and manganese-deposits of Georgia was begun by me while I was a member of the State Geological Survey, late in the season of 1900; and completed during the field-season of 1902. Separate reports on these deposits are in course of preparation, and as soon as completed they will be published as bulletins of the State Survey. It is the object of this paper to present some of the more important facts brought out in the field and laboratory study of the ocher-deposits of Bartow county, Georgia.

Historical Statement.

The first authentic record of ocher mined in Bartow county, Georgia, was in the year 1877, when Mr. E. H. Woodward began mining it on a property located near the limits of the town of Cartersville. The crude ocher as mined was hauled in wagons to Cartersville and there prepared for market. Mr. Woodward was engaged at the same time also in mining manganese-ores on the Dobbins property, six miles northeast of Cartersville.

Mining of the ocher on a small scale was continued on this and the adjoining property until 1890, when the Georgia Peruvian Ocher Co., supported by Western capitalists, became the owner of the property, and improved methods in the preparation of the ocher for market were introduced. Hauling to Cartersville was discontinued on account of the roads, and a plant for preparing the ocher was located at Emerson, two miles south of the mines. The first shipment of American ocher to Europe is reported to have been made in December, 1890, from the Cartersville mines, a consignment of 50 tons having been shipped to England.[1]

In 1890, two experienced ocher-men from the East, Mr. J. C. Oram of Vermont and Mr. E. P. Earle of New York, became interested in the company, and modern machinery and improved methods were brought into use. Mr. Oram was the first to introduce in the district the natural process of air-drying (sun)

[1] *Mineral Resources of the United States for* 1889 *and* 1890, p. 509.

in vats dug in the ground. The ocher-industry in Georgia properly dates from this year.

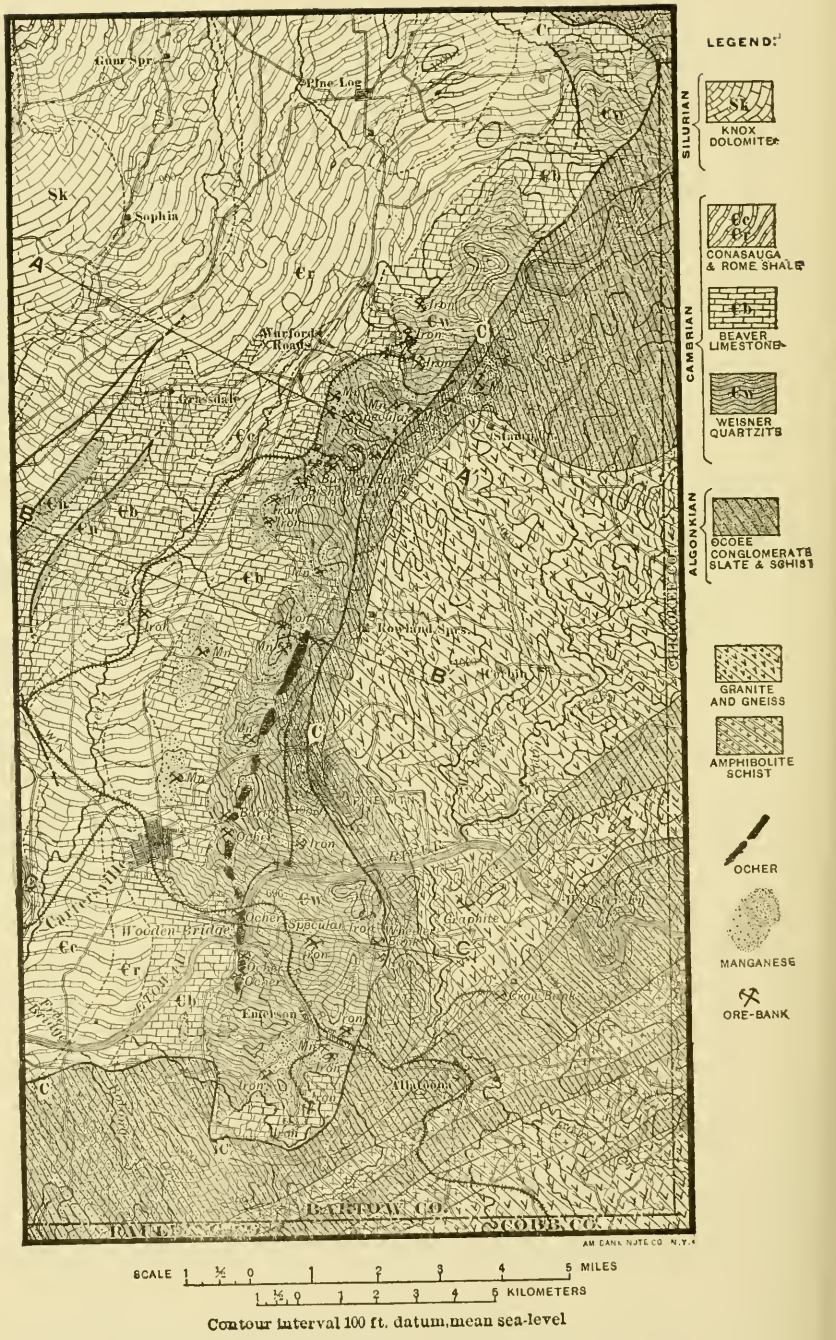
At present, four plants of large size and thoroughly equipped are engaged in mining and shipping the ocher in the Cartersville district: namely, the Georgia Peruvian Ocher Company; the Cherokee Ocher & Barytes Company; the Blue Ridge Ocher Company; and the American Ocher Company. The last plant was added in 1902. In every instance the mill for preparing the ocher is located at the mines, thereby reducing the cost of production from what it was in the early period, when mine and mill were separated by a considerable distance. The present plants are all located within two-and-a-half miles of the town of Cartersville, which is the shipping point.

Several unsuccessful attempts have been made to produce ocher at Rockmart, in the adjoining county, Polk, on the southwest, but each time the venture was abandoned.

Geology of the District.

The area here described, as shown on the accompanying map, Fig. 1, is limited to the southeastern portion of Bartow county, in northwestern Georgia; and it lies in the vicinity of the town of Cartersville, from which the district derives its name. It is one of the most productive ore-districts in the Southern Appalachians. Stratigraphically, the area is nearly equally divided between the Paleozoic formations on the west and the older crystalline metamorphic rocks of the Piedmont plateau and the Appalachian mountains on the east. The irregular line separating the two groups of unlike rocks marks the position of the Cartersville fault, which is the most important structural feature in the region.

As indicated in Fig. 1 (C, C, C, C), the rocks belong to two geologically distinct groups, which show marked differences as to age and kind. To the west of the fault-line the rocks are sedimentaries, and include quartzites, sandstones, shales, and limestones of Cambro-Silurian age. To the east of the fault-line the rocks are metamorphic crystallines, derived in part from original igneous masses and in part from original sediments.



Geological Map of the Cartersville District, Georgia, Showing the Distribution of the Ore-Deposits. (C. W. Hayes, *Trans.*, xxx., 405.)

Over parts of the area it is difficult to state definitely whether the original rock was igneous or sedimentary in origin. The altered sediments include conglomerates, slates, schists, and probably some of the gneisses. Wide variation in composition, and to a less extent structure, characterize the intrusive rocks, ranging from extremely basic rocks of the diabase type to acid granites, with perhaps diorite as the most common type. These igneous masses are no longer composed of massive rocks in structure, but, on account of intense pressure-metamorphism, they are now rendered highly schistose. On account of the absence of fossils in the sedimentaries of this series, and because of the rocks having every appearance of extreme age, Hayes has grouped them as Algonkian (Ocoee) in age.

The rock-sequence for the Paleozoic formations on the west side of the fault-line, named in descending order, becomes:

Silurian, . . .	4. Knox dolomite.
Cambrian, . . .	3. Rome and Conasauga shale.
	2. Beaver limestone.
	1. Weisner quartzite.

Of these formations only the Weisner quartzite is ocher-bearing and is of importance in the present connection, hence no description of the other formations will be given in this paper.

The Weisner Quartzite

The yellow ocher-deposits of the Cartersville district are limited exclusively to the Weisner quartzite. As shown on the map, the principal area of the quartzite forms a continuous narrow belt, approximately 15 miles long and several miles wide, in the central portion of the area mapped. Its eastern limit is the Cartersville fault, which marks the contact of the formation on the east with the rocks of the Ocoee series. Near the middle western margin of the map, faulting has exposed two additional narrow strips or bands of the quartzite, which are marked by the entire absence of ocher. As nearly as can be estimated the thickness of the quartzite in this area does not exceed 2,000 feet.

Lithologically, the formation is not entirely uniform, but in places it shows considerable variation, both in composition and texture, and in color as well. It is composed principally of a compact, fine-grained vitreous quartzite varying from light to dark gray in color, and in places containing beds of fine-grained conglomerate. Intercalated beds of a drab to darker colored siliceous shales of varying thickness, much crumpled, contorted and altered in places, are often met with. The formation contains much pyrite in the form of grains and crystals in places, and this mineral seems to be equally abundant in both the quartzite proper and the interbedded shale layers. The two mineralogically-unlike beds, shale and quartzite, are likewise ocher-bearing, and the difference in composition of the rock serves as a basis for making two grades of the ocher. The ocher found replacing the shales is prevailingly darker in color, because of the large proportion of admixed argillaceous or clayey matter derived from the shales, which cannot be separated from the refined ocher; while the ocher found replacing the quartzite proper is uniformly lighter in color, because of less admixed clay.

The effects of intense pressure-metamorphism are plainly evident in all parts of the quartzite formation, as shown in Fig. 3. As a result of the action of the compressive forces the quartzite layers have been sharply folded, and in addition the formation has been extensively crushed and shattered over most of its parts, especially in the ocher-bearing portions. So extensively crushed and shattered is the quartzite as indicated in some of the sections of the larger ocher-openings in the area, that it is almost impossible to determine the original bedding of the rocks. As often shown by its brecciated condition, the quartzite is presumably cut by numerous faults, but such lines of fracture, if they exist, have not been traced. As Hayes has stated, the physical forces were probably attended by increased chemical action, inferred from the formation of the ocher.

The composition of the quartzite proper is shown in the chemical analysis below made by the N. P. Pratt laboratory, in

Atlanta, Georgia, of specimens of the rock collected by me from different exposures of the formation.

	Per Cent.
Silica,	90.36
Alumina,	1.52
Iron sesquioxide,	0.57
Iron disulphide,	1.50
Lime,	0.27
Magnesia,	0.27
Soda,	0.43
Potash,	0.16
Manganese oxide,	none
Titanic oxide,	0.07
Barium sulphate,	4.46
Water,	0.31
Total,	99.92

Attention is called in the analysis to the percentages of iron disulphide (pyrite) and barium sulphate (barite) present in the rock. The occurrence of pyrite in the rock has been referred to above. The mineral barite is present to a greater or less extent in all the ocher-deposits of the district, but its presence in the fresh rock as a mineral constituent is nowhere indicated, either macro- or microscopically. The very small percentages of lime and alkalies shown in the analysis confirms the microscopic study of a large number of thin sections of the rock, in the nearly complete absence of feldspars. A few thin sections, however, showed sporadic grains of both microline and a striated plagioclase.

Topography.

With respect to surface configuration, the district may be divided into two nearly equal, unlike areas, as indicated on the accompanying map, Fig. 2. The line separating these two areas is an irregular one roughly paralleling the fault-line, and located from one to three miles west of it, and marking the contact between the Weisner quartzite and the Beaver limestone. The contour lines on the map, Fig. 2, mark off quite strongly the dividing-line between the two unlike areas.

That part of the district north of the Etowah river and

west of a line drawn northeastward through Cartersville marks a rather smooth plain, etched out of the soft shales and limestone of Cambrian age. Its average elevation above mean sea-level is between 800 and 900 ft. Slight inequalities in the form of irregular hills or minor ridges, rising from 100 to 125 ft. above the general surface of the plain, denote unreduced areas. Elevations of less than 800 ft.—from 750 to 775 ft.—are recorded in places along some of the larger stream-courses. Westward, the plain grades into the Knox dolomite plateau, a slightly more resistant magnesian limestone, whose general average elevation is but little above that of the Cartersville portion of the Paleozoic plain.

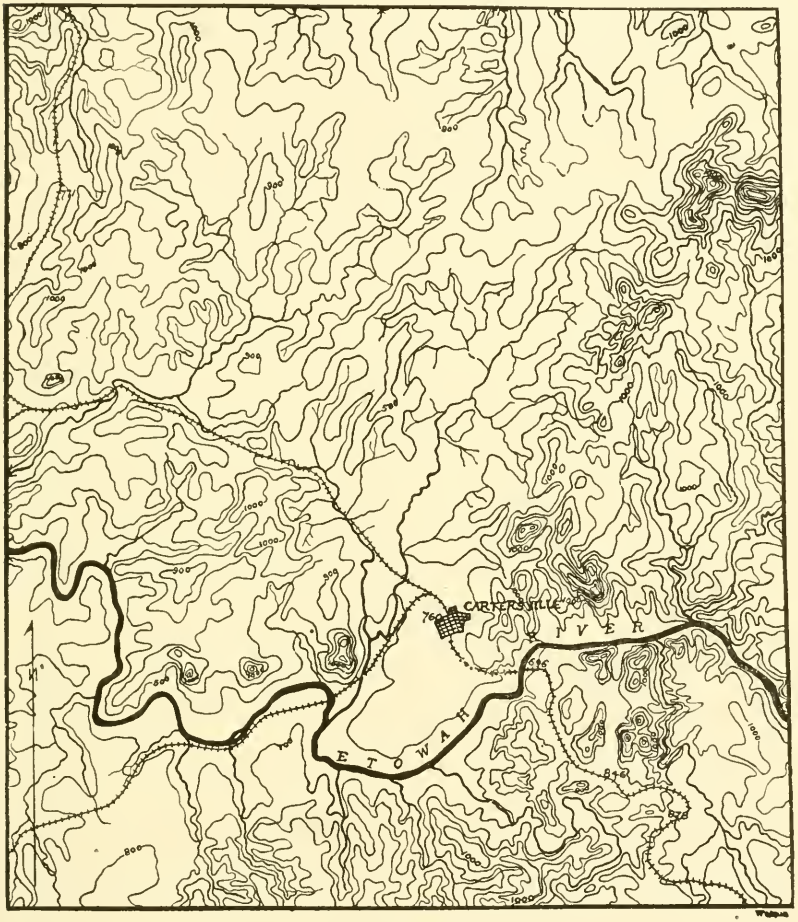
Beginning with, and including, the long central band of Weisner quartzite, that part of the mapped area to the south of the Etowah river and east of the plain already defined, is a second area whose surface is higher than that of the Paleozoic plain described and in marked contrast to it. The larger portion of this area forms the northwestward extension of the Piedmont plateau. Its general surface-elevation will average less than 1,000 ft. above mean sea-level, with numerous residuals in the form of irregular hills and ridges standing several hundred feet above the plateau surface. The surface then is an irregular one, trenched by comparatively deep and narrow stream-channels, in many places cut through the thick covering of decayed rock into the hard rock beneath. The northeast corner of the mapped area forms the equivalent lowering portion of the Appalachians, showing elevations of from 1,800 to 2,000 ft. This marks the roughest surface in the district. The higher and more roughened surface of the eastern half of the mapped area is etched out of geologically old, highly-tilted and disturbed metamorphic crystalline rocks, whose age for the most part is pre-Cambrian.

The entire district covered by the map is well watered. Its drainage is through numerous nearly north- and south-flowing streams tributary to the Etowah river, the master stream of the region, which has a general westward course, passing within a short distance south of the town of Cartersville.

Rock-Weathering.

The rocks of the area are very generally buried under a considerable thickness of residual clays derived from the decay of the underlying rocks by the usual action of the atmospheric

FIG. 2.



Topographical Map of the Cartersville District, Georgia. (Cartersville Topographic Sheet, *U. S. Geol. Survey.*) Contour-interval, 100 ft.

agents. Over many parts of the region exposures of the fresh

rock are seldom seen. A thickness of 100 ft. and more of the residual decay is frequent over the district. Difference in composition of the sub-terranes shows equally as marked a difference in the chemical and physical properties of the derived decay. The decay derived from the limestone is usually a deep-red ferruginous clay with or without admixed chert fragments, as the original rock was chert-bearing or not. That derived from the harder and more resistant quartzite is a light gray siliceous clay, in which the proportion of clay is usually relatively smaller than that derived from the sandstone. So strongly marked are the properties of the residual decay derived from the lithologically unlike sub-terranes, that the areas of originally fresh rock can usually be differentiated and traced with considerable accuracy by the decay.

The decay over the quartzite area is thickest in the valley-bottoms, and thinnest near and on top of the higher and steeper ridges. Along the steeper ridge-slopes exposures of the comparatively fresh and hard rock are not uncommon. On the ridge-tops large reefs and broken masses of the hard quartzite are frequent. The residual decay derived from the quartzite is largely admixed with fragments of various sizes of the quartz-rock in all stages of decay, from partially discolored hard rock to masses of loose or incoherent quartz-grains or sand.

The Ocher-Deposits.

As indicated on the the accompanying map, Fig. 1, the ocher belt has an approximate length of about eight miles in a nearly north-south direction. Traced by the outcroppings and the prospect-openings the belt is a very narrow one, not exceeding perhaps two miles in the widest point. It has its southernmost extension at and to the west of Emerson, about two miles south of the Etowah river, and is traced in a northward direction, about one mile east of Cartersville, to a point north and to the west of Rowland Springs. Beyond this point surface-indications disappear and no prospect-openings have been made, hence it is not possible to state definitely that this marks the extreme limit of the belt to the north.

Petrography of the Quartzite.

Some portions of the Weisner quartzite, as previously stated, contain interbedded siliceous shales of dark color. The quartzite proper varies from dense, nearly white, and vitreous massive beds, without distinct evidence of its fragmental character visible to the unaided eye, to massive beds of distinct granular quartzite of light and dark gray colors. By far the majority of the beds are composed of the granular quartzite in which the fragmental character is plainly evident. In the granular type the rock varies from an even-grained, fine-granular quartzite to a distinct conglomerate facies, in which the quartz-pebbles are usually of very small size.

Thin sections show it to be a rather pure quartz rock, composed of quartz-grains of somewhat variable size. In general the larger grains contain some inclusions of foreign mineral matter. Hardly a section examined failed to show, in a number of the larger grains, abundant hair-like needles probably of rutile, which are often bent and curved and in many cases broken. Usually the grains are considerably clouded by very fine innumerable dust-like particles, without definite arrangement, whose exact nature it was not possible to determine. Inclusions of slender prismatic crystals of apatite are not uncommon in some of the thin sections. The general shape of the larger grains is round. When examined in detail the outer margin of the grains invariably presents an irregular, angular outline, formed by the interlocking or dove-tailing of individuals in a surrounding mosaic of much smaller quartz-granules, which fills the entire interstices between the larger grains. This mosaic of finer quartz-particles bounding the larger grains is clearly the result of peripheral shattering from compression, a circumstance which is further confirmed by the general undulous extinction of the larger grains, and by the greatly crushed condition of the formation in the field.

Besides quartz, there occurs in some of the sections a slight sprinkling of feldspar grains, including microcline and a striated plagioclase, some calcite and occasionally grains of a titanifer-

ous iron oxide. Next to quartz, pyrite is the most abundant mineral. It frequently occurs as fresh grains and crystals; more often as partially and entirely oxidized in the form of iron oxide. In the latter case the original pyrite may be altered to a limonite pseudomorph, but generally the change has been rapid and a cavity preserving the outline of the pyrite, only slightly stained or partially filled with the iron oxide, forms the only evidence of the former presence of the pyrite. The mineral, both in the fresh and in the completely oxidized or altered condition, is often present in the same thin section. The stain of yellow iron oxide derived from the oxidation of the pyrite discolors the section for some distance around and away from the position of the original sulphide mineral. The staining extends the farthest along the sutures between the quartz-grains and the fracture-lines, which are present at times in the grains.

Microscopic study shows quite plainly the relations of the ocher to the quartzite and its mode of occurrence in the rock. After a careful study of a number of thin sections under the microscope of the ocher-stained rock from different parts of the belt, my results accord so closely with Hayes's description that I quote him in full. He says:[1]

"When the transition-rock is examined under a microscope, the character of the transition can be seen even more clearly. The more compact portions, which are only slightly stained with iron, are seen to be composed of a transparent ground-mass, threaded with minute cavities, which penetrate the rock in all directions and contain a fine dendritic growth of iron oxide. The latter occurs only rarely in isolated grains, but generally in clusters of minute grains or fibers, attached to each other and branching irregularly from a central stem. They have no trace of crystal form. Passing toward the ore-body, these minute passages become larger and increase in frequency, until only a finely branching siliceous skeleton remains, the greater part of the rock having been replaced by the iron oxide. Under polarized light, the transparent ground-mass is broken up into an aggregate of small quartz-grains, penetrated in all directions by the iron oxide. The latter does not lie between the individual grains, but passes through them, as though the ground-mass were quite homogeneous. The process of replacement is never complete; for all the ocher contains more or less sand. When this is washed clean from the iron oxide, it is found to differ from ordinary sand-grains

[1] *Trans.*, 1901, xxx., 416.

in having extremely irregular outlines. This sand, as might be anticipated from the microscopic structure of the slightly altered quartzite, is evidently composed, not of the original grains of the rock, but of detached portions of the irregular siliceous skeleton, which, in the intermediate stages of replacement, holds the iron oxide in its cavities."

A chemical analysis made at the N. P. Pratt laboratory in Atlanta, Georgia, of specimens of the quartzite collected by me is given on page 205 of this paper.

The ocher occurs only in the fresh Weisner quartzite and its decay; and exposures of the fresh rock indicate that it occupies an extensively shattered zone in the formation. It is found in place in the fresh quartzite and in a similar position in the residual clays derived from the decay of the quartzite. Examples of both occurrences are abundant in the region.

Associated Ore-Deposits.

Besides ocher, the district is one of the largest and principal producers of the ores of iron and manganese in the State. In addition to these, some barite has been mined and shipped from the area. The latter mineral, while rather largely distributed over portions of the region, has not proved profitable, for the reason that it is rarely sufficiently concentrated for mining alone, and it is not of sufficient purity to make a desirable grade of marketable baryta.

The ores are often very closely associated with each other, but recent study of them shows the genesis of the types of ore-deposits to have been quite different. The deposits of yellow ocher are rarely entirely free from some admixture of one or all of the other types of ores mentioned. These are usually present only in small quantity in the ocher, and generally in sufficiently large fragments to admit of nearly complete separation from the ocher by the usual process of cleansing.

In many cases manganese oxide, in the form of very finely disseminated grains or powder, is not entirely freed from the refined product, and it is claimed that a faint greenish cast is thereby imparted to the ocher. The deposits of ocher and manganese are frequently in juxtaposition, and the openings

employed in working the manganese are now used for mining the ocher. Such occurrence is well illustrated on the property of the Blue Ridge Ocher Company, where large quantities of manganese-ores were formerly mined, and the tunnels and shafts are now utilized for removing the ocher. On the same property a large quantity of hard and porous spongy masses of limonitè, occurring as lenses and irregular seams in the ocher beds, was being removed with the ocher during the summer of 1902.

At the Etowah river, on the Georgia Peruvian Ocher Company's property, several miles southeast of Cartersville, large clusters and groups of barite crystals are formed in the pockets of ocher and in the fractures and caverns of the quartzite. The barite often occurs in divergent groups of massive tabular crystals, giving crested appearance, grading into both straight and curved laminated masses.

Chemical Composition of the Ocher.

The chemical composition of both the crude and the refined ocher is shown in the table of analyses below, made by the N. P. Pratt laboratory, in Atlanta, Georgia.

Table of Chemical Analyses of the Crude and Refined Ocher.

	Samples.							
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Fe_2O_3, . . .	72.29	56.29	65.49	54.60	67.37	61.40	67.32	62.79
Al_2O_3, . . .	5.55	10.15	7.20	6.68	6.85	7.14	5.86	6.94
FeO, . . .	0.46	0.39	----	----	----	----	----	----
MnO_2, . . .	0.87	0.54	1.80	1.50	2.04	2.00	----	----
SiO_2 (free sand), .	6.65	8.94	7.76	17.42	6.54	11.89	9 14	6.20
SiO_2 (combined as silicates), . . .	3.98	9.49	6.85	10.08	6.61	5.84	6.35	9.78
H_2O at 105° C, . .	0.55	2.08	0.40	0.48	0.96	0.46	0.78	0.50
H_2O above 105° C, .	9.22	11.34	10.50	9.24	9.63	9.37	9.60	----
Total, . .	99.57	99.22	100.00	100.00	100.00	100.00	99.05	----

I. Crude ocher from Mansfield Brothers' property. Lot No. 462, 4th District, 3d Section, Bartow county, Georgia.

II. Crude ocher from the John P. Stegall property, near Emerson, Bartow county, Georgia.

III, IV, V and VI. Refined ocher from the Blue Ridge Ocher Company's property. Lot No. 490, 4th District, 3d Section, Bartow county, Georgia. Furnished by courtesy of the Manager, Captain John Postell, Cartersville, Georgia.

VII. Refined ocher from the Cherokee Ocher & Barites Company's property, one mile east of Cartersville. Furnished by courtesy of the President, Mr. T. W. Baxter, Atlanta, Georgia.

VIII. Refined ocher from the American Ocher Company's property. Lot No. 475, 4th District, 3d Section, Bartow county, Georgia. Furnished by courtesy of the Manager, Mr. Waite, Cartersville, Georgia.

The analyses are sufficiently explanatory, and attention need only be called to one feature, namely, the high percentage of ferric oxide. Assuming all the ferric oxide to be combined with water[1] in the proportion to form limonite, and calculating on this basis the percentage amount of limonite in each analysis, we find an average of 78.33 per cent. for the eight analyses. This means that about one-fourth of the entire product consists of foreign mineral matter, in the form of impurities that cannot be separated from the hydrous iron oxide (ocher) by the present methods of cleansing. Field- and laboratory-studies show this admixed mineral matter to consist largely of clay and very finely divided quartz-particles, with, in many cases, smaller amounts of manganese oxide. Notwithstanding these facts the yellow ocher of the Cartersville district is one of the very best mined in the United States, and is the equal of most of the foreign ochers of this color.

Mode of Occurrence of the Ocher.

As previously defined, the yellow ocher belt in Bartow county is entirely limited to the Weisner quartzite of lower Cambrian age. Field-study shows that the ocher occurs in both the hard and fresh quartzite and in the residual clays derived

[1] Only in one case, analysis II of the table, is there sufficient water indicated in the analyses to satisfy all of the ferric oxide according to the formula $2Fe_2O_3 . 3H_2O$.

from the decay of the quartzite. So far as mining developments have been made in the area, the ocher has nearly equal occurrence in the fresh and in the decayed quartzite. At every point examined, its position in the residual clays is in all respects similar to that in the hard and fresh rock. Its occurrence in the fresh and in the altered rock can best be described separately.

Occurrence in the Fresh Rock.—Abundant opportunity is afforded for studying the mode of occurrence of the ocher in the fresh rock over many parts of the area, from the good natural exposures of the rock. (See Figs. 4, 5 and 6.) For the study of the ocher in its relations to the fresh rock, the best section is at the wooden bridge over the Etowah river, two miles southeast of Cartersville, where the river has cut across one of the quartzite ridges and where extensive mining has been done by the Georgia Peruvian Ocher Company. Here the quartzite has been extensively crushed and shattered from compression, so that it is difficult to determine the original bedding of the rock (Fig. 4).

Concerning the occurrence of the ocher at this locality, Doctor Hayes says:[1] "The ocher forms a series of extremely irregular branching veins, which intersect this shattered quartzite without any apparent system. They frequently expand into bodies of considerable size; and when the ocher is removed, rooms from 6 to 10 ft. in diameter are sometimes left, connected by narrow winding passages. The mining of the ocher has left the point of the ridge completely honey-combed with these irregular passages and rooms.

"The contact between the ocher and the inclosing quartzite is never sharp and distinct, but always shows a more or less gradual transition from the hard vitreous quartzite, to the soft ore which may be easily crushed between the fingers. The quartzite first becomes stained a light yellow, and loses its compact, close-grained texture. This phase passes into a second, in which the rock is perceptibly porous, having a rough fracture

[1] *Trans.*, xxx., 415--416.

and a harsh 'feel,' and containing enough ocher to soil the fingers. In the next phase the ocher preponderates, but is held together by a more or less continuous skeleton of silica, although it can be readily removed with a pick. The final stage in the transition is the soft yellow-ocher, filling the veins, which crumbles on drying, and contains only a small proportion of silica in the form of sand-grains.

"The intermediate zone between the pure ocher and the quartzite is usually a few inches in thickness, although it may be several feet between the extremes, and, on the other hand, sometimes only a fraction of an inch."

Microscopic study of a large number of thin sections of the ocher-charged quartzite collected from all parts of the area discloses, with but few exceptions, either the former or the existing presence of pyrite. In many of the sections at least a part of the pyrite is entirely fresh and unaltered, but in a majority of them the pyrite has been completely oxidized, leaving the original space occupied by the mineral only partially filled, as a rule, by its alteration-product, iron oxide. Between these two extremes, of scant iron oxide partially lining the cavity and pseudomorphic limonite filling the entire cavity, all gradations are traced.

The full and accurate description quoted above from Hayes of the ocher-occurrence in the fresh quartzite in the section exposed at the wooden bridge over the Etowah river, similarly applies to the remaining exposures over the area studied by me, in which sections show the occurrence of ocher in the fresh rock.

Occurrence in the Residual Clays.—The area is one of profound atmospheric decay, and exposures of the fresh rock are rarely seen, except on the steeper ridge slopes and crests. The ocher cuts the enclosing clays in a very irregular manner, forming a series of irregular branching deposits which correspond to veins in the fresh rock. The ore-bodies narrow and widen, thin and thicken, throughout their extent. Irregularity results both as to the vertical and the lateral distribution of the deposits. The contact between the ocher-bodies and the sur-

rounding clays is never entirely sharp, but a more or less gradual transition from the clays to the pure ocher is usually shown. The ocher-charged clays at the point of contact lessen considsiderably in the ocher-content a short distance away, and is entirely absent from the clays at some distance from the point of contact. As in the case of the ocher-bodies in the fresh rock, the transition zone between the clay and the pure ocher is quite variable, from a few inches or less to as many feet between the extremes.

The field conditions make it entirely plain that the position of the ocher in the clays is in all respects similar to that in the fresh rock. Evidence pointing to leaching or concentration of these bodies upon weathering of the rock is lacking. Somewhat extensive mining on the properties of the Blue Ridge Ocher Company, the Cherokee Ocher & Barytes Company, and the American Ocher Company, affords the best opportunity for studying the mode of occurrence of the ocher in the residual clays.

Origin of the Ocher.

The mode of occurrence of the ocher when viewed in its relations to the character and structural conditions of the enclosing rock forms the strongest possible argument for the theory favoring its formation from solution. All evidence, both from field- and laboratory-study goes to prove that the deposition of the ocher has taken place, not by simple filling of cavities and fissures in the rock, but by a molecular replacement of the original rock. The principal evidence in proof of this is summed up as follows:

1. In nearly every instance of exposure of the fresh rock over the ocher-belt the rock is found to be extensively crushed and shattered and cut in all directions with lines of fracture, by compression. This mechanical action was more than probably accompanied by heat, and the zone of crushed rock afforded ready and natural passage-ways for underground circulating waters, both of which were conducive or favorable to increased chemical action.

2. The contact between the ocher and the surrounding quartzite is never sharp and distinct, but is marked by a gradual transition from the hard quartzite to the soft ore. The transition-zone between the hard quartzite and the soft ocher varies from a few inches to several feet in thickness between the two extremes.

3. The exceedingly irregular character of the ore-bodies and their distribution in the enclosing rock furnish further evidence. The shattered rock is cut in all directions by exceedingly irregular branching veins of the ocher, which narrow and widen, thin and thicken indiscriminately, without apparent regard to system or uniformity.

4. Microscopic study of the transition-portion of the rock makes plain the relations of the ocher to the quartz-rock and the mode of ore-occurrence in the rock. The iron oxide (ocher) usually cuts across the quartz-grains instead of lying between them. This replacement process is never complete, but all the ocher contains more or less free quartz-grains distributed through it. The grains are very irregular in outline, which distinguishes them from ordinary quartz- or sand-grains, and they were evidently formed from solution.

5. Finally, the replacement-hypothesis is strengthened by the general appearance of the rock which affords in places evidence of solution and redeposition of the silica. Small cavities are frequently observed penetrating the quartzite, and lined with very small crystals of quartz deposited from solution. Also, the skeleton of silica holding the ocher together and the sand-grains disseminated through the purer beds of soft ocher appear to have been derived by deposition from solution, rather than to be composed of grains of the original rock.

The source of the iron oxide, and the solution of the quartz of the rock and its replacement by the iron oxide (ocher) have been previously discussed in some detail by Hayes, [1] and need not be repeated here. After a microscopic study of a large number of thin sections of the ocher-charged and the ocher-

[1] *Trans.*, xxx., 403.

free quartzite, I feel reasonably certain that an additional source of the iron oxide not considered by Hayes, is derived from the oxidation of disseminated pyrite through the quartzite. The source of iron oxide from this direction may possibly have been of only secondary importance.

Economic Features.

Methods of Mining.

The ocher-deposits to be mined in the Cartersville district form extremely irregular branching veins, which intersect the rock in almost every direction. The ore-bodies may occur enclosed in the hard and fresh quartzite, or they may be entirely enclosed in the residual decay derived from the quartzite. The bodies of pure ocher are usually soft and clay-like in character, and the ore is easily mined with the pick and shovel. They are generally exposed along the slopes and summits of the quartzite hills and ridges.

On those properties in the district where systematic mining has been done, the method employed consists of tunnels driven into the ridge, from which drifts are worked at suitable points. In this way a number of levels have been worked, one above the other, on several of the properties. Occurrence of the ocher in the fresh rock, as on the Georgia Peruvian Ocher Company's property at the wooden bridge across the Etowah river, at times necessitates blasting. (See Fig. 4).

Timbering is necessary in the tunneling, as caving is apt to occur. The undergound-mining is also extensive enough to necessitate tramways and lights. The tram-cars are drawn in and out of the mines either by mules or by means of steam and cable. Both are in use in the Cartersville mines.

Preparation of the Ocher.

The only preparation necessary involves the separation of the ocher from its mechanically admixed impurities as mined, which consist principally of clay, sand, and manganese oxide. These are freed from the ocher by a process of washing in running water, floating, and settling of the ocher in vats, from which the water is evaporated.

With one exception, the form of washer in use at the different plants in the district is of the kind used in washing the manganese and brown iron-ores, known as the log-washer, and has been described by me in a former paper,[1] entitled "The Geologic Relations of the Manganese Ore-Deposits of Georgia."[2]

The form of washer in use at the Blue Ridge Ocher Company's plant was planned for the purpose of diminishing the grinding and rubbing action of the log-washer, and thereby decrease proportionately the resulting percentage of finely divided impurities, principally sand and manganese dioxide, which would be floated with the ocher. The washer consists of a V-shaped box about 7 ft. in length, 5 ft. high, and 3 ft. wide at the top. In the bottom of the box is fastened a 3-in. pipe with ⅛-in. perforations along the top at intervals of about 1.25 in. The water is introduced into this pipe, and passes into the box through the perforations in the pipe. Over this pipe revolves a shaft set with 1-in. pins so arranged that those of one row fall just halfway between those of the next, giving a spacing of 2-in. between pins, if they were aligned in the same row.

By this arrangement the ocher is sufficiently disintegrated without being subjected to the grinding and rubbing action of the ordinary log-washer. The water containing the suspended particles of ocher overflows at the top of the washer-box into a line of troughs, through which it passes into the settling-vats. The ocher is further purified by the settling of a portion of the impurities along the bottom of the troughs in transit to the vats. After the overflow becomes thin, showing that the ocher in the charge is about exhausted, a long narrow door at the bottom of the washer is raised and the sand, clay, etc., mixed with some ocher, are washed through and carried off in a trough as waste.

I am reliably informed by the manager of this plant that the washer of the size above stated easily handles from 25 to 30 tons of ocher per day of ten hours, and that all the necessary

[1] *Trans.*, xxxiv., p. 207.

[2] Reprint, *Bulletin Scientific Laboratories of Denison University*, 1904, Vol. XII, Art. X, pp. 146-198.

work, including cleaning of the troughs, etc., is readily performed by three ordinary laborers.

The ocher passes from the washer, through a line of troughs, into a series of settling-vats dug in the ground, and is exposed throughout the day to the direct heat of the sun. After it has settled, and as much as possible of the water siphoned off by rubber-hose, the remainder of the water is expelled by evaporation. As soon as it is stiff enough to be handled, the ocher is removed from the vats and placed on drying-racks under a shed where the drying-process is completed. (See Fig. 7). The time required for the evaporation of the water from the ocher in the vats sufficient to admit of handling will average about ten days in clear summer weather. It requires from eight to twelve days of similar weather to complete the drying on the racks before the ocher can be pulverized.

Evaporation is either by natural means—exposure to the heat of the sun—or by artificial means promoted by steam-heating. Several of the plants in the district are fully equipped for both natural and artificial evaporation. The artificial drying is in vats or tanks, arranged in series, in which iron-pipes are run at close intervals along the sides and bottoms for steam-heating. Drying by this method requires usually not longer than one or two days, when the ocher is ready to be removed to the racks and the drying continued for the usual time, from eight to twelve days, before it is dry enough to be pulverized. While the time is much shortened by the steam-drying over that of the natural evaporation by the sun, the ocher is less desirable than the sun-dried material; the reason for this being that near the pipes the heat is strong enough to dehydrate partially or calcine the ocher, changing its color from yellow to dark red. For this reason some plants in the district have not included an equipment for artificial drying.

After being thoroughly dried, the ocher is pulverized and packed under steam-pressure in barrels and bags of uniform size, ready for shipment.

Fig. 8 presents a view of the plant of the American Ocher

Company, two-and-a-half miles northeast of Cartersville. The drying-racks are shown in the rear of the main building.

Uses.

The principal use made of the Cartersville ocher at present is in the manufacture of linoleum and oil-cloths. For this consumption the principal markets are in England and Scotland, to which the bulk of the Cartersville product is exported. Some of it is used in the United States for a similar purpose. It is also used to a limited extent in the manufacture of paints. By calcining, the ocher is converted into a desirable dark red pigment.

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THE LEOPARDITE (QUARTZ PORPHYRY) OF NORTH CAROLINA.

By THOMAS L. WATSON

Granville, Ohio, August, 1904.

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THE LEOPARDITE (QUARTZ PORPHYRY) OF NORTH CAROLINA.[1]

By Thomas L. Watson.

INTRODUCTORY STATEMENT.

While engaged, during the past summer, in a study of the granites of North Carolina for the State Survey, opportunity offered for examination in the field of the well-known and interesting rock called "leopardite," which occurs near Charlotte in Mecklenburg county. Knowledge of the occurrence of this rock in the state dates back many years, and brief descriptions of it have been published from time to time by different writers, as noted below in the appended references.

In 1853 Dr. Hunter[2] briefly described, megascopically, the general appearance, including locality, of the leopardite found near Charlotte, Mecklenburg county, North Carolina. He says: "It is noticed by Professor Shepard, under the head of feldspar, as the leopard stone of Charlotte, North Carolina." Professor Shepard regarded it as composed of compact feldspar and quartz spotted by the oxides of iron and manganese. Hunter suggested the propriety of retaining the name "leopardite," for the reason that it is quite characteristic of a rather unique rock. In the same paper the author refers to a second locality in Lincoln county, North Carolina, where leopardite had recently been found. Concerning the character of the rock in Lincoln county, he says: "The pervading stripes are, however, generally finer; and when broken diagonally, it presents a handsome aborescent appearance."

In 1862 Dr. F. A. Genth[3] described the leopardite occur-

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[1] Published by permission of the state geologist of North Carolina.

[2] C. L. Hunter, "Notices of the Rarer Minerals and New Localities in Western North Carolina," *American Journal of Science*, Vol. XV, (1853, 2d ser.), p. 377.

[3] F. A. Genth, "Contributions to Mineralogy," *ibid.*, Vol. XXXIII, (1862, 2d ser.), pp. 197, 198.

ring near Charlotte as a true porphyry, and gave some general results of a microscopical examination of thin sections of the rock, including a chemical analysis. Still a third locality in North Carolina where leopardite is reported to be found is referred to by Genth, namely, near the Steel mine in Montgomery county.

More recently the leopardite occurring near Charlotte has been noted by Merrill[1] and Lewis[2]. After briefly describing the general appearance of the rock, Professor Merrill makes further statement of its economic value. In connection with his work on the building stones of North Carolina, Lewis visited the locality to the east of Charlotte, where the leopardite is exposed, and, so far as contained in published accounts of the rock known to me, he was the first to note its true geological occurrence.

Quartz porphyries in association with other closely similar acid volcanic rocks are developed, in places, over the central and the northwestern parts of the state. So far as known at present, the areas of acid volcanic rocks are confined to the volcanic belt which skirts the western margin of the Triassic sandstone in the eastern Piedmont region,[3] and to several of the extreme northwest counties[4] of the state. These rocks show no essential differences, so far as they have been studied, from certain areas of similar ones which occur and are traced at irregular intervals northward along the Atlantic border region of North America as far as Newfoundland.

Of those occurrences in North Carolina, the quartz porphyry found near Charlotte is the only one visited by me that

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[1] George P. Merrill, Stones for Building and Decoration (New York, 1897), 2d ed., pp. 272, 273.

[2] J. V. Lewis, Notes on Building and Ornamental Stone, *First Biennial Report of the State Geologist, N. C. Geological Survey*, 1893, p. 102.

[3] George H. Williams, "The Distribution of Ancient Volcanic Rocks Along the Eastern Border of North America," *Journal of Geology*, Vol. II (1894), pp. 1-32; J. S. Diller, "Origin of Palcotrochis," *American Journal of Science*, Vol. VII (1899, 4th ser.), pp. 337-42.

[4] A. Keith, *Bulletin No. 168*, U. S. Geological Survey, p. 52; *Geologic Atlas of the United States*, "North Carolina-Tennessee, Cranberry Folio," 1903.

shows the characteristic spotted appearance so suggestive of the name "leopardite." Except for the mottled or spotted appearance produced by rounded black areas of metallic oxides, the Charlotte rock differs but slightly, if at all, in essential characters from quartz porphyries described from other localities. (See table of analyses on p. 229).

LOCATION AND OCCURRENCE.

The leopardite is exposed in a number of small outcrops at Belmont Springs, about one and a half miles east of Charlotte. Beginning on top of the hill, several hundred yards above the spring the rock is traced in outcrops over the surface for a distance of a quarter to a half mile in a north 30° east direction. It forms a true dike, intersecting a medium textured and colored, sheared and crushed, biotite granite; and, so far, as it was possible to determine, the dike nowhere exceeds twenty-five feet in width, with a smaller average cross-section. A small opening in one of the outcrops from which some of the rock has been blasted reveals a sharp contact between the quartz porphyry and the inclosing granite.

MEGASCOPIC DESCRIPTION.

The fresh rock is nearly white, tinged the faintest greenish in places, and penetrated by long parallel streaks or pencils of a dead black color. When broken at an angle to the direction of the pencils, the rock surface appears spotted with rounded, irregular black points, ranging in size up to half an inch in diameter. At times the roundish points are somewhat irregular and only partially developed, as shown in the lower left half of Fig. 1. These may be crowded close together over the surface, as seen in the figure, or they may be entirely absent from some areas and irregularly distributed at wide intervals over others, as indicated in Fig. 3. Indeed, the black points are reported to fail entirely in the rock as the dike is traced northward, when the rock assumes a uniformly light color throughout. However, every outcrop and specimen of the rock seen by me contained them.

A section cut parallel to the direction of the pencils presents a surface streaked with long, somewhat irregular, though roughly parallel, black lines, more or less perfect dendritic or fern-like forms (Figs. 2 and 3). I was shown recently a large slab of the rock collected from one of the outcrops since my examination in the summer of 1903, which, for perfection and delicacy of tracery in fern-like forms, was beautiful beyond description. The black streaks or pencils which characterize the rock are composed of a staining of the oxides of manganese and iron.

The rock is cryptocrystalline in texture, breaking with a conchoidal fracture, and is intensely hard and tough. Minute quartz crystals of doubly terminated pyramidal faces are distributed through the rock at irregular wide intervals. These are nowhere abundant in the rock, but they are always present to some extent, and consist both of the light-colored and dark, smoky, vitreous quartz. Indeed, unless carefully examined, the rock would ordinarily be pronounced non-porphyritic in texture, so small and scattering are the porphyritically developed quartzes. Megascopically, porphyritic texture is nowhere particularly emphasized in the rock, but its slight development is best seen on a weathered surface of the stone, where the unaltered quartz crystals, though few in number and widely scattered, contrast more strongly with the weathered surface and appear more conspicuous than in the fresh rock. Feldspars are also porphyritically developed, as described below, though the phenocrysts are difficult of differentiation in hand specimens of the rock.

MICROSCOPICAL DESCRIPTION.

In thin sections the rock consists of a holocrystalline groundmass and scattered small porphyritic crystals. Flow-structure is not exhibited in the groundmass, and the phenocrysts indicate no orientation with respect to each other. The groundmass is micro-granitic in structure, though some sections show much of the micro-granophyric structure, with an irregular radial, spherulitic, structure developed in greater or less

proportion in all of the sections studied. When they form complete spheres, which is rarely the case, they usually exhibit somewhat irregular ragged peripheries, and further show usually between cross nicols a very indefinite black cross. The form of the grains in the typical micro-granitic areas of the groundmass is sharp and allotriomorphic to partially idiomorphic. The principal groundmass minerals are feldspar and quartz, with much light-colored mica, and an occasional inclusion of prismatic apatite and zircon. Irregular minute grains of iron oxide are scattered through the sections, and stained areas from manganese and iron oxides, forming the dark spots and pencils in the hand specimens, occur. The thin sections are characterized by the complete absence of ferro-magnesian minerals.

Feldspar is apparently in largest quantity, and is composed of both potash and plagioclase species. Occasional grains of microcline are recognized which show the characteristic microcline twinning. The unstriated feldspar grains so strongly resemble quartz that it is impossible in many cases to distinguish them without the application of optical tests. Optical tests show the plagioclase to be albite—a circumstance entirely confirmed by the chemical analysis of the rock given below in the table of analyses under I, in which only the barest trace of lime is indicated, with soda in large amount and in excess of the potash. Some of the plagioclase exhibits polysynthetic twinning according to the albite law, and at times assumes lath-shaped forms. The feldspar substance is generally fresh, but the individual grains are usually rendered dark by abundant, closely crowded, minute, dark, dust-like particles, the identity of which could not be made out.

Quartz is of the usual kind and presents no noteworthy features, further than its occurrence in small mosaics of interlocking grains, which occupy at times distinct areas in some of the thin sections.

Light-colored mica, tinged a faint yellow, is very generally distributed through the sections, in the form of irregular minute shreds, groups, and aggregated masses, the folia of which are at times imperfectly arranged radially about a common center.

A part, at least, of the mica is clearly secondary, while some of it is yet doubtful as to origin, whether primary or secondary. Its general appearance and association in the sections might very well indicate secondary formation for all of it.

Phenocrysts of both quartz and feldspar occur in well-developed idiomorphic forms, usually in rectangular and squarish cross-sections. In the thin sections studied, phenocrysts of feldspar are more abundant than quartz; and while the porphyritic texture is poorly developed in the hand specimens, it is very pronounced in the thin sections. The quartz phenocrysts show irregular fractures free from impurities, strained shadows, and occasionally inclose grains of feldspar. The porphyritic feldspars show in part broadly twinned bands of plagioclase, and untwinned orthoclase. These are frequently rendered nearly opaque from innumerable, closely crowded, dark inclusions not identifiable, along with minute spangles of colorless mica. Zonal structure is rarely observed, and cleavage is usually wanting. Around the borders of several of the feldspar phenocrysts slight embayments, produced by incipient resorption, are noticeable.

Several of the sections were so cut as to include areas of the black pencils which characterize the rock, megascopically. These are distinguished, microscopically, from the white portions of the groundmass only by a distinct medium-to-dark yellowish-brown staining, somewhat resembling that of limonite stain frequently observed discoloring tiny areas of the rock, derived from the partial leaching of any iron-bearing constituent in igneous rocks. No definite source of the staining was entirely indicated in any of the sections, but the areas clearly represent percolation of solutions of manganese and iron salts through the rock. Why the definite arrangement into long pencils and dedritic forms manifested megascopically, evidence is again lacking, for the textural relations of the minerals in the discolored areas are precisely the same microscopically, as for other portions of the rock. The character of the staining suggests that the spotted and streaked appearance of the rock is a

superficial phenomenon, and perhaps does not extend to any very great depth.

CHEMICAL COMPOSITION.

The chemical composition of the rock is given in analysis I of the table of analyses. The analysis of leopardite was made by Dr. F. A. Genth from the freshest fragments of the groundmass obtainable. The most striking features of the analysis are (1) the very acid character of the rock, manifested in the high SiO_2 content; (2) the nearly complete absence of CaO and MgO; and (3) the increased Na_2O which is in excess of the K_2O. The analysis, however, harmonizes closely with the microscopic study of thin sections of the rock, for the absence of ferromagnesian minerals accounts for the very slight amount of MgO present, while the practical absence of CaO and the large percentage of Na_2O prove the plagioclase to be albite, as indicated above by the microscope.

TABLE OF ANALYSES.

	I	II	III	IV	V
SiO_2	75.92	79.75	79.57	73.12	72.85
Al_2O_3	14.47	10.47	11.41	14.27	13.78
Fe_2O_3	0.88	0.64	0.20	0.51	1.87
FeO	----	0.92	0.70	0.26	0.36
MgO	0.09	0.13	a little	0.24	0.42
CaO	0.02	0.15	0.21	1.10	0.87
Na_2O	4.98	1.36	3.46	3.43	4.14
K_2O	4.01	6.01	3.52	4.90	4.49
H_2O–110°C.	----	0.08	0.18	0.68	0.22
H_2O+110°C.	0.64	0.60	0.61	0.73	0.54
TiO_2	----	0.15	0.11	0.08	0.44
P_2O_5	----	trace	trace	0.03	0.13
ZrO_2	----	0.05	----	----	----
MnO	----	trace	----	0.06	0.06
SrO	----	trace	----	trace	----
BaO	----	0.06	0.05	trace	----
Li_2O	----	trace	----	trace	----
NiO	----	----	----	----	0.20
CO_2	----	----	----	0.77	----
Total	100.01	100.37	100.02	100.18	99.87

I. Quartz porphyry (leopardite), one and a half miles east of Charlotte, Mecklenburg county, North Carolina. *American Journal of Science*, Vol. XXXIII (1862, 2d ser.), p. 198. F. A. Genth, analyst.

II. Quartz porphyry—two and a half miles northwest of Blowing Rock, Watauga county, North Carolina. Petrographic data by Arthur

Keith. Contains quartz and orthoclase, with subordinate sericite, chlorite and biotite. W. F. Hillebrand, analyst. *Bulletin No. 168*, U. S. Geological Survey, p. 52.

III. Spherulitic rhyolite—Sam Christian gold mine, Montgomery county, North Carolina. Described by J. S. Diller, *American Journal of Science*, Vol. VII (1899, 4th ser.), p. 341. W. F. Hillebrand, analyst. *Bulletin No. 168*, U. S. Geological Survey, p. 53.

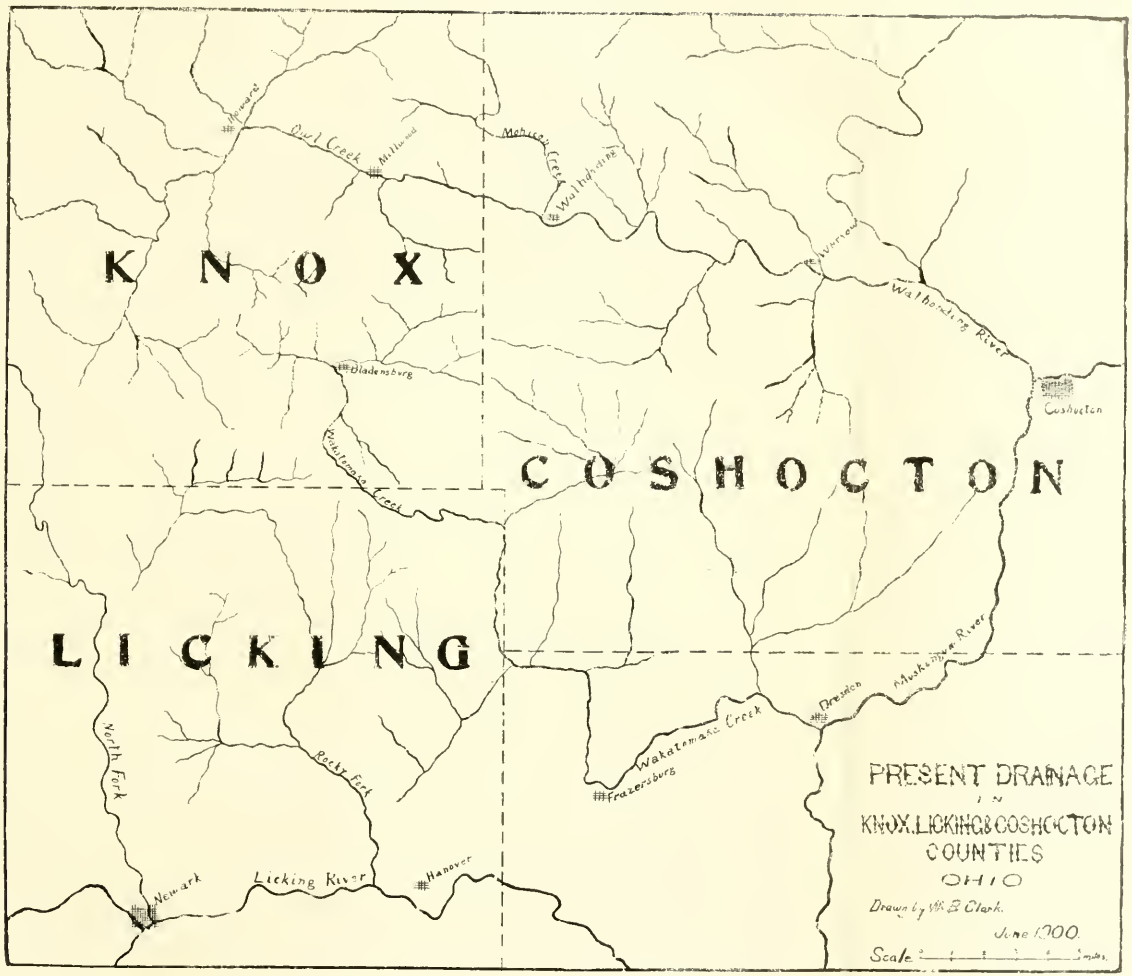
IV. Quartz porphyry. Yogo Rock, sheet at head of Belt and Running Wolf Creeks, Little Belt Mountains, Montana. Described by Weed and Pirrson. *Twentieth Annual Report*, Part III, U. S. Geological Survey, pp. 520 ff. W. F. Hildebrand, analyst. *Bulletin No. 168*, U. S. Geological Survey, Vol. III, p. 125.

V. Quartz porphyry.—Six miles east of Ironton, Missouri. Described by E. Haworth, *Annual Report*, Missouri Geological Survey, Vol. VIII, 1894, p. 181. Melville, analyst.

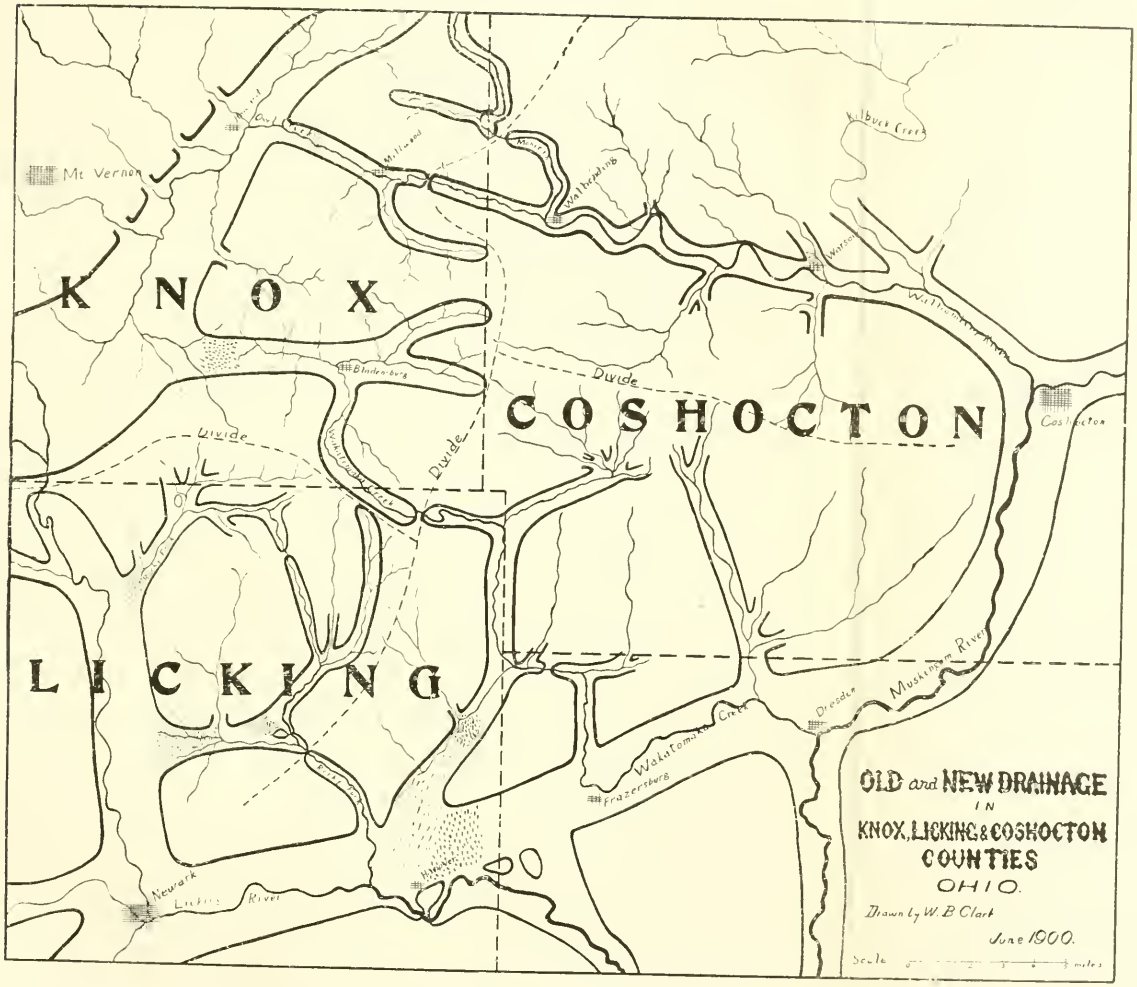
This analysis is compared in the table with a recent, more detailed one (II), of a quartz porphyry occurring in the northwestern part of the state, and with a spherulitic rhyolite (III) found east of the Charlotte locality in Montgomery county; and with analyses IV and V of well-known quartz porphyries occurring in other parts of the United States. A perusal of the figures given in the table will make clear the general similarity of the rocks, notwithstanding the rather striking differences indicated in some of the constituents.

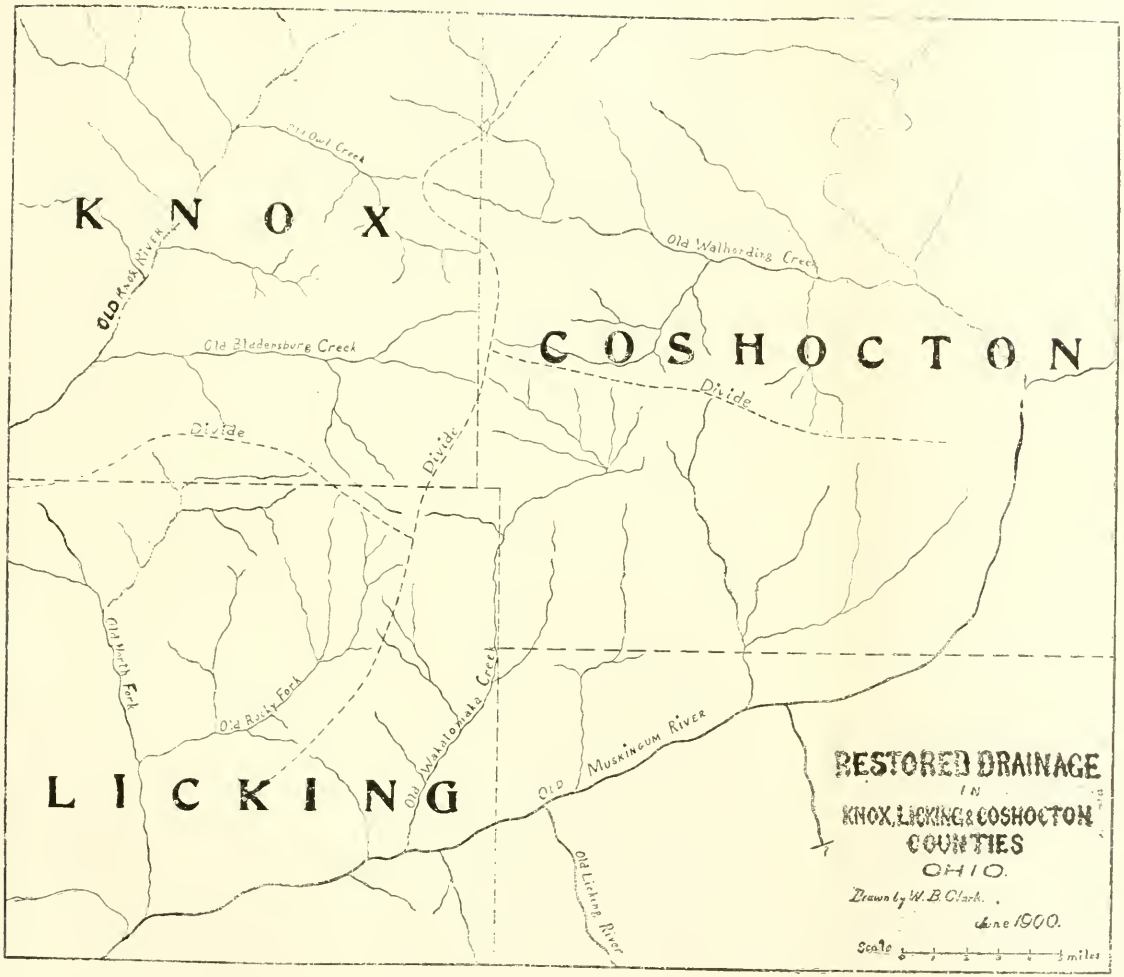
WEATHERING.

In some exposures of the leopardite the weathered surface of the rock, which is still hard and firm, presents a lusterless, dead, chalk-like whiteness, the black spots of which are more or less bleached, changed from black to a reddish-brown in color. This alteration is brought out fairly well in Fig. 4, which is a photograph of a hand specimen of the partially weathered rock, reproduced one-half natural size. Bleaching of the spots is more emphasized along the top of the specimen, shown in the figure (4) in the contrasted lighter color of these spots to others in the same figure When Fig. 4 is compared with those of the fresh rock, Figs. 1, 2 and 3, it is noticeable that all the spots in it have undergone some leaching, as indicated in their color being less intense or deep than for those in the fresh specimens of the rock.



CLARK—Drainage Modifications.


Mt Vernon
K N O X
Bladensburg
Divide
Divide
Divide
C O S H O C T O N
Coshocton
L I C K I N G
Newark
Licking River
Wakatomika Creek
Frazersburg
Dresden
Muskingum River
OLD and NEW DRAINAGE
IN
KNOX, LICKING & COSHOCTON
COUNTIES
OHIO.
Drawn by W. B. Clark
June 1900.
Scale



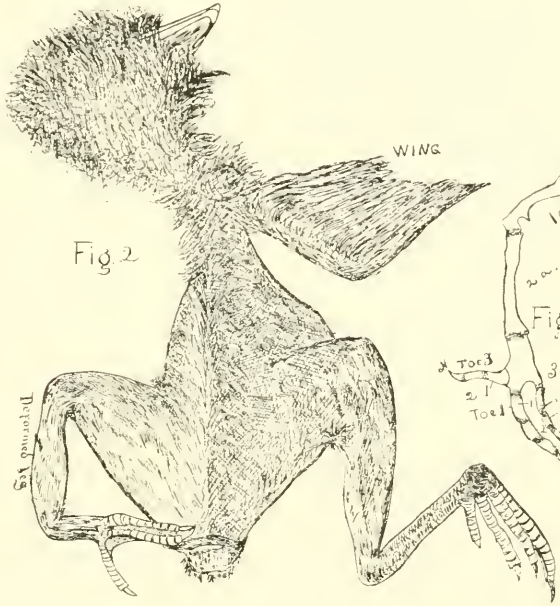
CLARK—Drainage Modifications

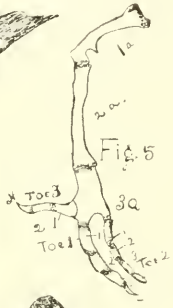
Stone Mountain, Georgia. An unreduced residual of granite, rising 686 feet in elevation above the surrounding Tertiary Piedmont plain. Seven miles in circumference at its base. (Photograph by W. S. Y.)

A view of one of the quarries opened on the northwest side of Stone Mountain, Georgia. Aplite-pegmatites exposed in places over the floor of quarry, now clear of the quarry waste shown in the foreground of the photograph. (Photograph by W. S. Y.)

Fig 1
Normal Leg.
Wing

Fig 6
1a
2a
3a
Toe 3
Toe 2
Toe 1


WING
Fig 2
Deformed Leg


1a
2a
Fig 5
3a
Toe 3
2
Toe 1

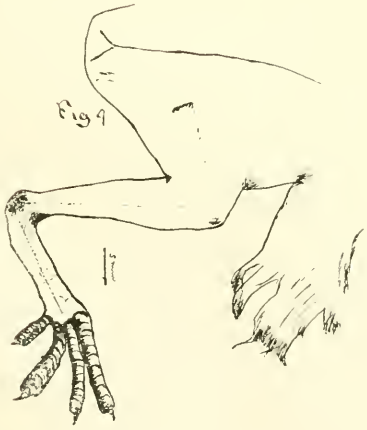


Fig 4

Deformed Leg.
Fig 3
line

FIGURE 1.—HALLOWAY MINE.

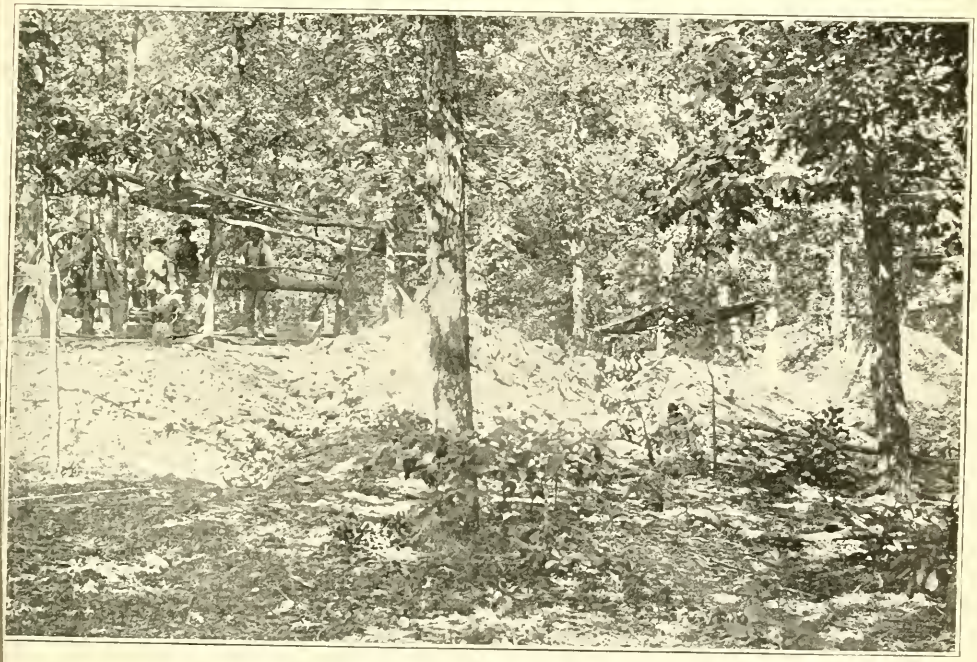


FIGURE 2—SHAFT NUMBER 2—WALKER MINE.

COPPER MINES, PERSON COUNTY, NORTH CAROLINA

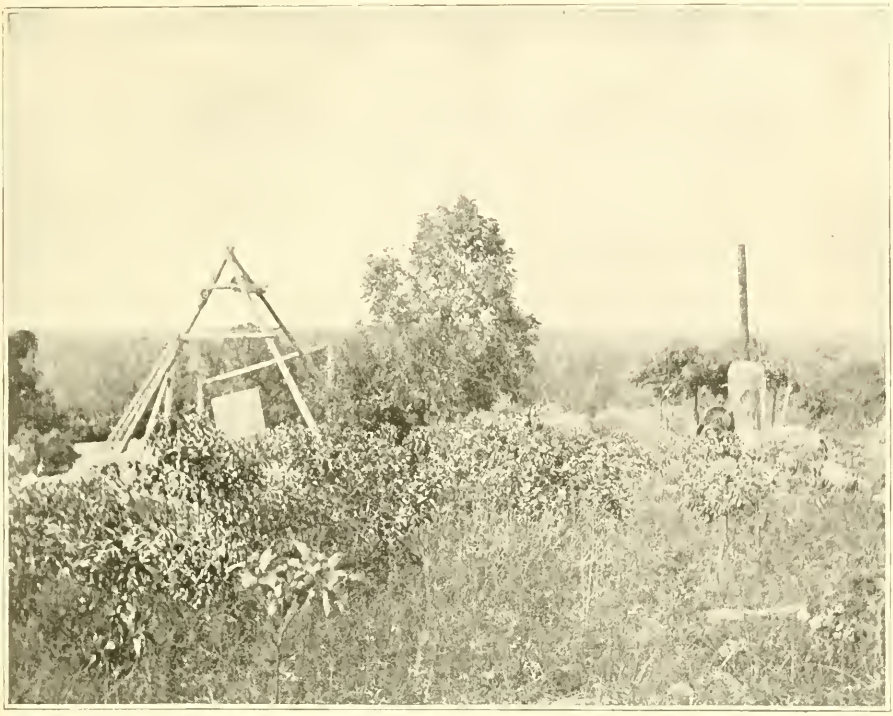


FIGURE 1—SHAFT NUMBER 3

FIGURE 2—SHAFT NUMBER 4

HIGH HILL COPPER MINES, HALIFAX COUNTY, VIRGINIA.

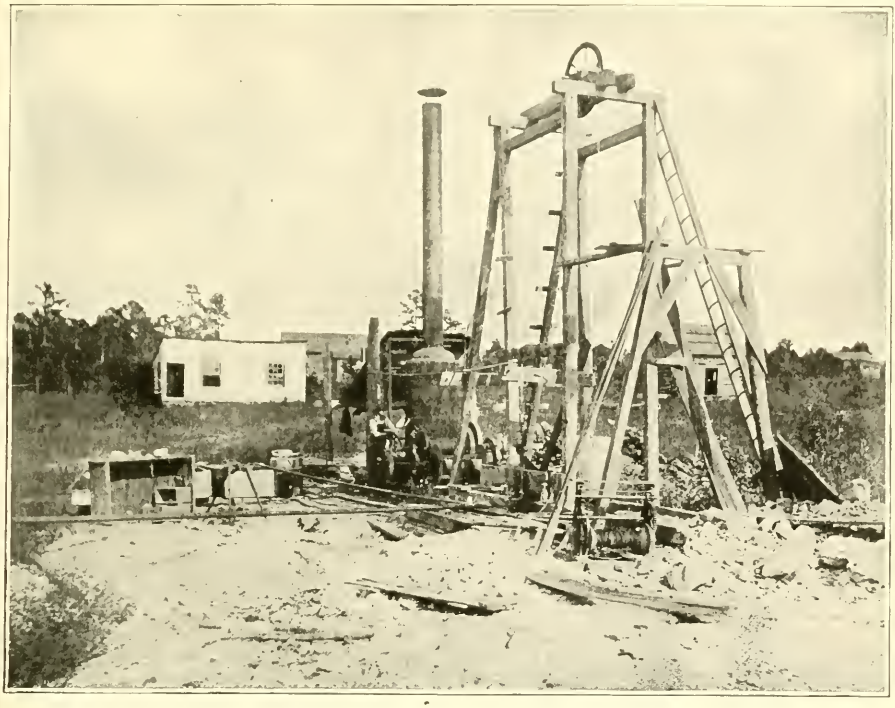


FIGURE 1—SHAFT NUMBER 1—YANCEY MINE

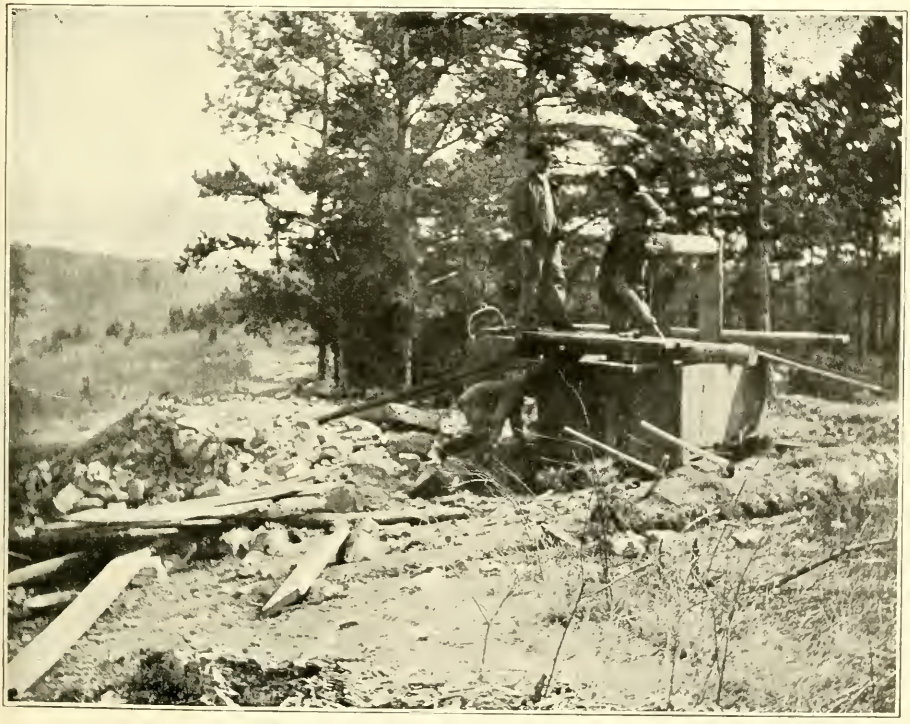


FIGURE 2—FOURTH OF JULY SHAFT

COPPER MINES, PERSON COUNTY, NORTH CAROLINA.

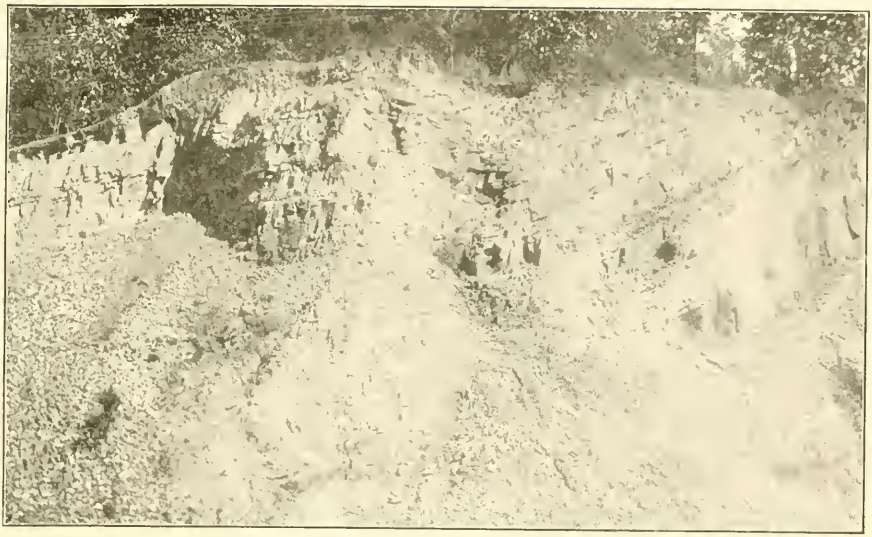


FIG. 3—Cut Along Western & Atlantic R. R., 1.5 Miles SE. of Cartersville, Showing Folded and Crushed Weisner Quartzite.

FIG. 4—Part of Section Through Quartzite Ridge, Exposed by the Etowah River, at the Wooden Bridge, 2 Miles from Cartersville.

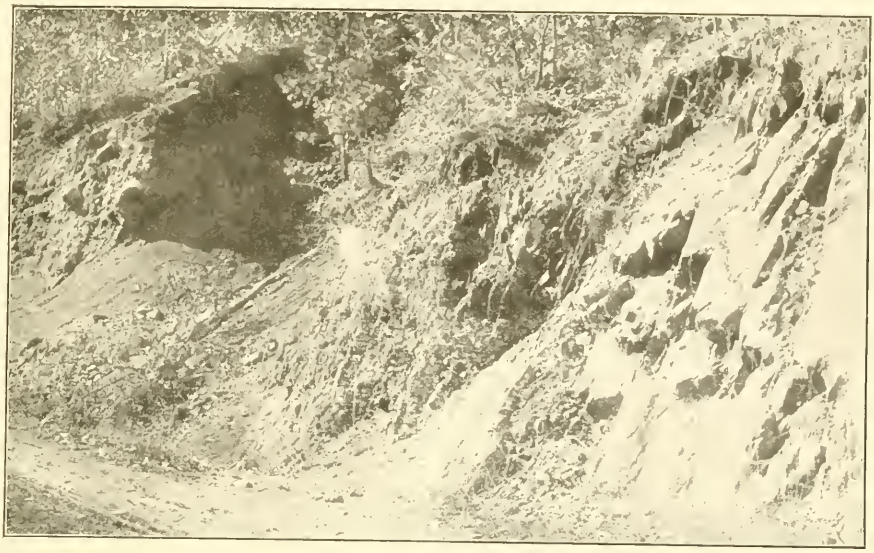


FIG. 5—Ocher-Pit Between Tilted and Crushed Quartzite Along Rowland Springs Road on the Blue Ridge Co.'s Property.

FIG. 6—Ocher-Pits in Quartzite, 1.5 Mile SE. of Cartersville. The Quartzite-Layers are Nearly Covered with Crumbling Rock.

FIG. 7—Portion of an Ocher-Plant Near Cartersville, Showing Drying-Shed and Racks.

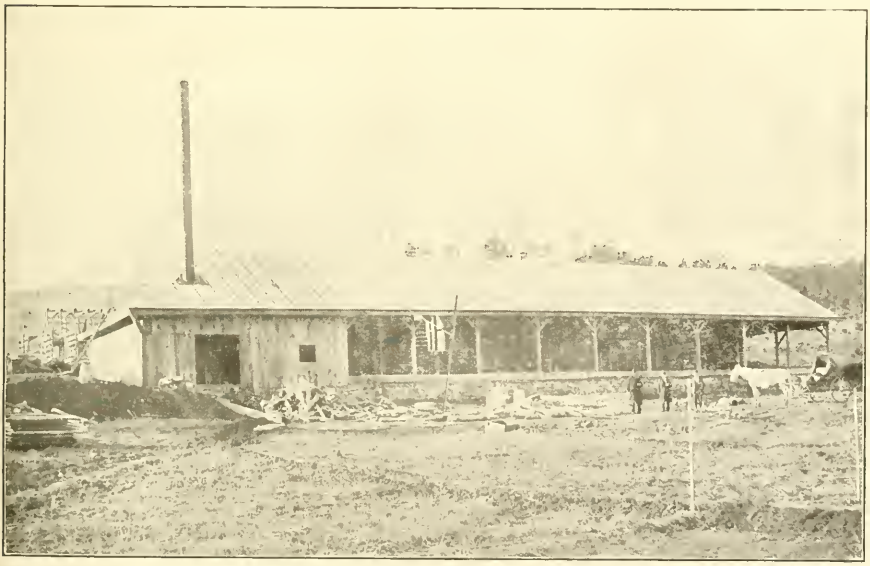


FIG. 8—Plant of the American Ocher Company, 2.5 Miles NE. of Cartersville.

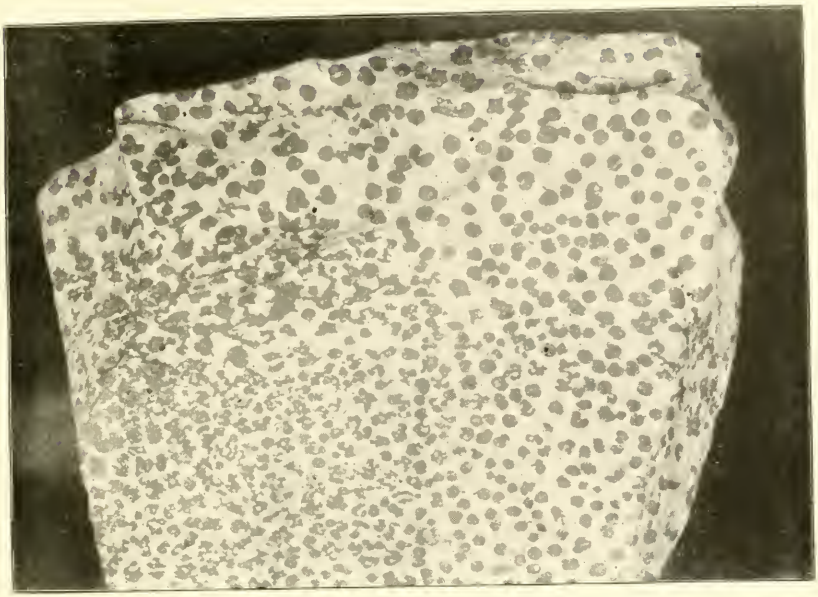


FIG. 1. - View showing the spotted appearance of the rock on a surface broken at right angles to the longer direction of the pencils. Photographed from a hand specimen. (One-half natural size.)

FIG. 2.—View showing approximately parallel black streaks and pencils on rock surface broken parallel to the direction of the pencils. Photographed from hand specimen. (One-half natural size.)

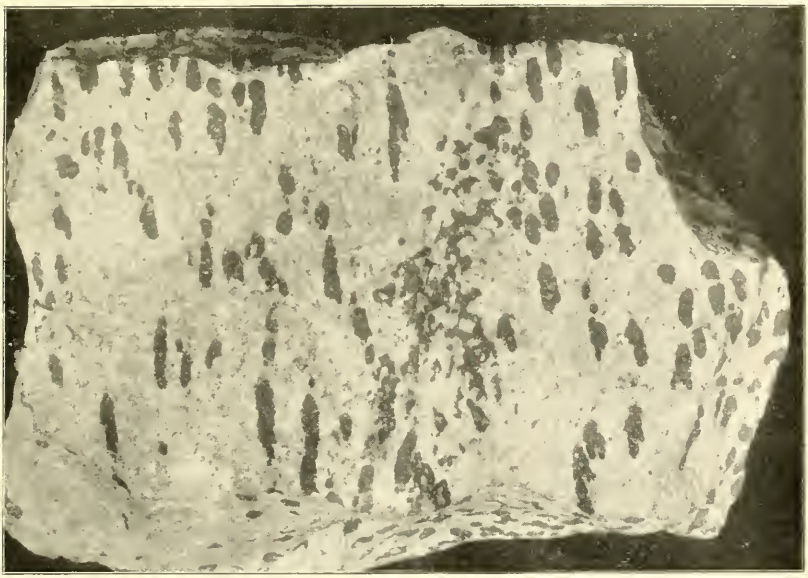


FIG. 3.—View showing partially spotted and partially streaked rock, with tendency toward arborescent form manifested near the middle of the picture. Surface broken at an angle intermediate between that of Figs. 1 and 2, Plate XIII. Photographed from hand specimen. (One-half natural size.)

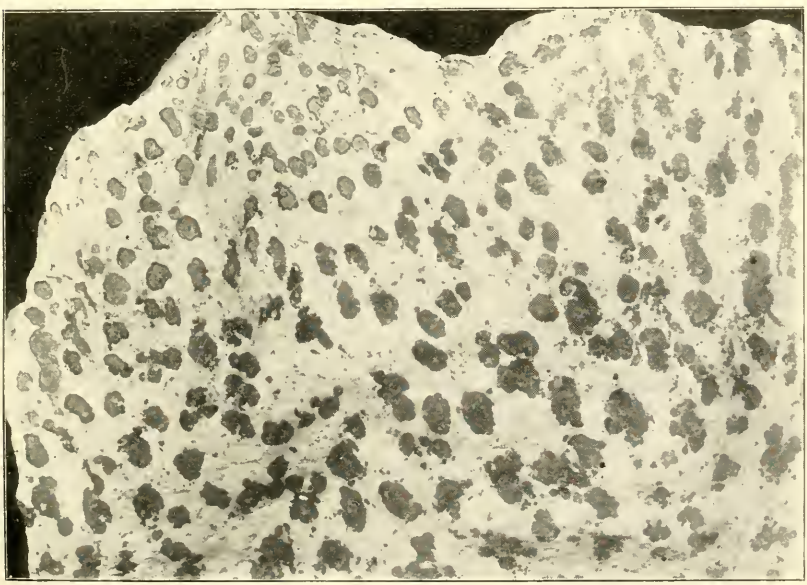


FIG. 4.—View showing weathered surface of the rock. Partial leaching of the dark spots is emphasized in the upper portion of the picture. Photographed from hand specimen. (One-half natural size.)

C. L. HERRICK

3 2

Date Due

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